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Geology Of The Highvale Study Site: Plains Hydrology and Reclamation Project

Heritage Fund

Alberta

LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

Report No. RRTAC 87-11

GEOLOGY OF THE HIGHVALE STUDY SITE: PLAINS HYDROLOGY AND RECLAMATION PROJECT

by

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Prepared for

The Reclamation Research Technical Advisory Committee

of

THE LAND CONSERVATION AND RECLAMATION COUNCIL

1987

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STATEMENT OF OBJECTIVE

The recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide government and Industry staff with up-to-date technical information to assist in the development of guidelines and operating procedures. The report is also available to the Public so that interested individuals similarly have access to the best available information on land reclamation topics.

ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from the Department of Forestry, Lands and Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The Reclamation Research Program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the Research Program, the Council appointed the Reclamation Research Advisory Committee (RRTAC). The Committee first met in March 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands and Wildlife, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for Reclamation Research.

Additional information on the Reclamation Research Program may be obtained by contacting:

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RECLAMATION RESEARCH REPORTS

** 1. RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp.

DESCRIPTION: This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

** 2. RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi, and H.F. Regier. 160 pp.

DESCRIPTION: Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

N/A 3. RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker, and P.F. Polster. 2 vols, 541 pp.

DESCRIPTION: Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their fitness for use in Reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

N/A 4. RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp.

DESCRIPTION: This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

N/A 5. RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stien, R. Leitch, and G. Lutwick. 253 pp.

DESCRIPTION: Presents nine technical papers on the chemical, physical and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites and use of ash as a soil amendment. Workshop discussions and summaries are also included.

N/A 6. RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp.

DESCRIPTION: Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system. Vol. 2 comprises the keyword index and computer access manual.

N/A 7. RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp.

DESCRIPTION: This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available from the Alberta Environment Library.

N/A 8. RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp.

DESCRIPTION: Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

N/A 9. RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp.

DESCRIPTION: Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

N/A 10. RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz. 123 pp.

DESCRIPTION: Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics and resulting water quality. Mitigative measures and priorities were also discussed.

N/A 11. RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp.

DESCRIPTION: This is a review and analysis of information on planting stock quality, rearing site preparation, planting and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

*** 12. RRTAC 84-1: Land Surface Reclamation: A Review of International Literature. H.P. Sims, C.B. Powter, and J.A. Campbell. 2 vols, 1549 pp.

DESCRIPTION: Nearly all topics of interest to reclamation including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

** 13. RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp.

DESCRIPTION: This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

* 14. RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 15. RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 2 vols, 676 pp.

DESCRIPTION: This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symboints in various amended spoil types.

** 16. RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz. 416 pp.

DESCRIPTION: Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

* 17. RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 18. RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp.

DESCRIPTION: The report examines the critical issue of settling pond design and sizing and alternative technologies.

** 19. RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp.

DESCRIPTION: Reconstructed soils representing different materials handling and replacement techniques were characterized and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

* 20. RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp.

DESCRIPTION: In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

** 21. RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp.

DESCRIPTION: This report summarzies the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

** 22. RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Program. A. Maslowski-Schutze. 71 pp.

DESCRIPTION: This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

* 23. RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden at the Battle River Mining area in east-central Alberta to support post-mining land use. Both groundwater quantity and quality are evaluated.

* 24. RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp.

DESCRIPTION: This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

* 25. RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 26. RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp.

DESCRIPTION: This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed.

** 27. RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp.

DESCRIPTION: Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual included provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

** 28. RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik, and D.G. Walker. 174 pp.

DESCRIPTION: This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area.

** 29. RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (compiler). 218 pp.

DESCRIPTION: Technical papers were presented which describe: the mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

* 30. RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

* 31. RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp.

DESCRIPTION: The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the east slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed.

** 32. RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp.

DESCRIPTION: The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions.

* 33. RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp.

DESCRIPTION: The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

* 34. RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp.

DESCRIPTION: This report describes a study to evaluate the influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

** 35. RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp.

DESCRIPTION: This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

** 36. RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus maps.

DESCRIPTION: The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. A series of maps supplement the report.

Available from:

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11510 Kingsway Avenue
Edmonton, Alberta T5G 2Y5

* A $5.00 fee is charged for handling and postage.
** A $10.00 fee is charged for handling and postage.
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N/A Not available for purchase but available for review at the Alberta Environment Library, 14th Floor, 9820-106 Street, Edmonton, Alberta T5K 2J6.

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PREFACE

This is one of a series of reports that presents the findings of the Plains Hydrology and Reclamation Project (PHRP), an interdisciplinary study that focuses primarily on hydrologic aspects of reclamation of surface coal mines in the plains of Alberta. This research has been conducted by the Alberta Research Council, as part of the Alberta Government's Reclamation Research Program. The program is managed by the Alberta Land Conservation and Reclamation Council and is supported by the Heritage Savings Trust Fund.

The focus of the PHRP is to develop a predictive framework that will permit projection of success for reclamation and impact of mining on water resources on a long-term basis. The predictive framework is based on an understanding of processes acting within the landscape so that, in the future, mine sites that are not totally analogous to those that have been studied can be evaluated as well.

The project involves a holistic approach to reclamation by integration of studies of geology, hydrogeology, and soils, not only in the proposed mining area, but also in the adjoining unmined areas. This approach permits the assessment of impacts and long-term performance, not only in reclaimed areas, but also in the surrounding area.

The research of the PHRP has been directed toward the following two major objectives and eight subobjectives.

Objective A

To evaluate the potential for reclamation of lands to be surface mined. The focus is on features of the landscape that make it productive in a broad sense not restricted to revegetation. This objective was organized into five subobjectives.

1. To assess and evaluate the potential for long-term degradation of reclaimed soils through salt build up.
2. To assess and evaluate the effectiveness of topographic modification and selective placement of

materials to mitigate deleterious impacts on chemical quality of groundwater.

3. To assess the availability of water supply in, or beneath, cast overburden to support post-mining land use, including both quantity and quality considerations.
4. To evaluate the productivity potential (capability) of post-mining landscapes and the significance of changes in capability as a result of mining.
5. To assess and evaluate limitations to post-mining land use posed by physical instability of cast overburden.

Objective B

To evaluate the long-term impact of mining and reclamation on water quantity and quality. This objective was organized into three subobjectives.

1. To assess and evaluate the long-term alteration of quality of groundwater in cast overburden and surface water fed from mine spoil as a result of the generation of weathering products.
2. To assess and evaluate infiltration, groundwater recharge, and groundwater-surface water interactions within cast overburden.
3. To characterize the groundwater chemistry generated within cast overburden.

Studies directed at these objectives began in 1979 at the Battle River site in east-central Alberta. Work began in 1982 at a second study area at Highvale Mine south of Lake Wabamun. Significant progress had been made on all project objectives by the end of the first phase of study in March 1984. This present series of reports summarizes the state of our knowledge at the end of this first phase of study. Work is now continuing on the Phase II objectives to gain an even greater understanding of the complex physical and chemical processes in reclaimed landscapes.

This report is one of a series that describes the geology, soils, and groundwater conditions at the Highvale Study site. It provides a geologic framework within which the various project subobjectives have been studied. The report does not address the project objectives directly, but rather provides supporting background for the entire study.

This report makes no attempt to synthesize the total volume of geologic data that is available for the Highvale site. Several exhaustive studies synthesizing hundreds of drill holes have been prepared by Monenco for TransAlta Utilities Ltd.

Although much of this body of data was examined in preparation of the present report, it was not considered necessary or desirable to produce a synthesis of the geology at that level of detail. The purpose of the present study was to establish a summary of site geology on the basis of detailed evaluation of the relatively small amount of drill-hole data obtained by the PHRP within the context of this larger existing data framework. The level of detail necessary was that to provide a framework for our studies of hydrogeology and reclamation. The greater level of detailed synthesis required by TransAlta Utilities Ltd. for mine planning was not considered to be necessary for this purpose.

ACKNOWLEDGEMENTS

The research undertaken by the PHRP was supported by funds from the Alberta Heritage Savings Trust Fund. The research was conducted for the Alberta Land Conservation and Reclamation Council. The assistance of TransAlta Utilities Ltd. in providing access to the study site, as well as in providing geologic data, is gratefully acknowledged. Brian Lyons of Monenco Ltd., discussed geological data and interpretations with the author.

ABSTRACT

At the Highvale Mine site, the Ardley Coal Zone, which is considered to be the top of the Scollard Member of the Paskapoo Formation, consists of six persistent coal seams, with the upper two being the thickest and most important. Overlying the coal zone, the Paskapoo Formation consists of a sequence of continental fluvial sediment, which has been subdivided into four stratigraphic units. A dark grey shale unit, Unit A, directly overlies the coal. This shale, which commonly contains coal stringers and bentonite beds, is interpreted to have been deposited within a very low-energy environment, likely ponds or lakes within the flood-basin zone of a large river valley. Overlying Unit A is Unit B, a complex sequence of sediment that, in places, consists of thick, apparently structureless sandstone, and in other places consists of interbedded shale, siltstone, and sandstone. This unit represents both channel depositional facies and near channel, overbank depositional facies. At most sites, particularly in the areas of present mining, the thick sequence of Unit B comprises most of the overburden. Unit C, which overlies Unit B, consists of interbedded shale, mudstone, and minor siltstone. This unit represents a return to flood-basin deposition. Unit D is a salt and pepper sandstone, which caps topographically high areas, largely in the southern and western part of the study area. It is not clear whether Unit D represents in-place rock or whether it consists of glacially transported material from Unit B.

Overlying the bedrock overburden is a variable thickness of glacial drift. The drift consists of clayey to silty diamecton (till), clayey lake sediment, and abundant disturbed and transported blocks, lenses and masses of included bedrock material. The composition of the glacial drift is highly variable depending on the abundance of incorporated bedrock material.

Smectite is the dominant clay mineral in the bedrock overburden. Carbonate minerals are generally present in the bedrock in small and variable amounts, most commonly as cement or secondary

mineralization. Pyrite, although present, is a very minor constituent of the overburden.

Sandstone beds in the Scollard Member below the Ardley Coal Zone generally have very low porosity, from about 2 to 10 percent, and are inferred to have correspondingly low permeability. The low porosity results from the angular nature of the grains, combined with grain overgrowths and cement of silica and carbonate and abundant clay mineral fillings in the pores.

1. INTRODUCTION

The Highvale Study site is located at the Highvale Mine of TransAlta Utilities, about 80 km west of Edmonton on the south side of Lake Wabamun (Figures 1 and 2). The geology of the site is discussed in this report, which describes both the bedrock and overlying glacial drift. The report also describes the chemical, physical, and mineralogical properties of these deposits. The data base for this part of the report was compiled from several overburden characterization programs that were completed prior to the PHRP study (Figure 3).

The bedrock in the study area consists of nonmarine rock of late Cretaceous and early Paleocene age. Coal beds of the Ardley Coal Zone, which are being mined at the site, are considered to be lower Paleocene in age (Singh 1984, personal communication). Considerable controversy surrounds the classification of these rocks and the placement of the Cretaceous-Tertiary boundary within them. The terminology that has been accepted in this report follows Irish (1970) and Lerbekmo et al. (1979) and is summarized in Figure 4.

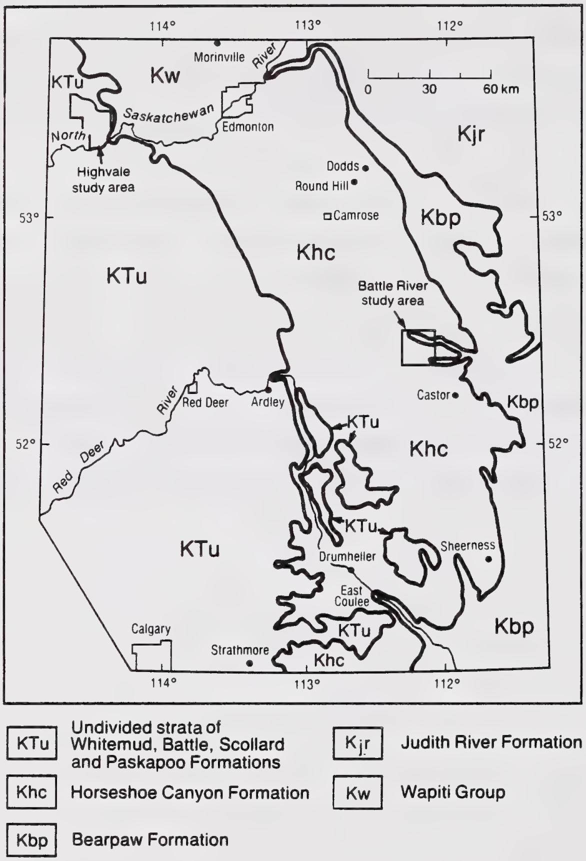

Figure 1. Map showing location and geologic setting of the Highvale study area.

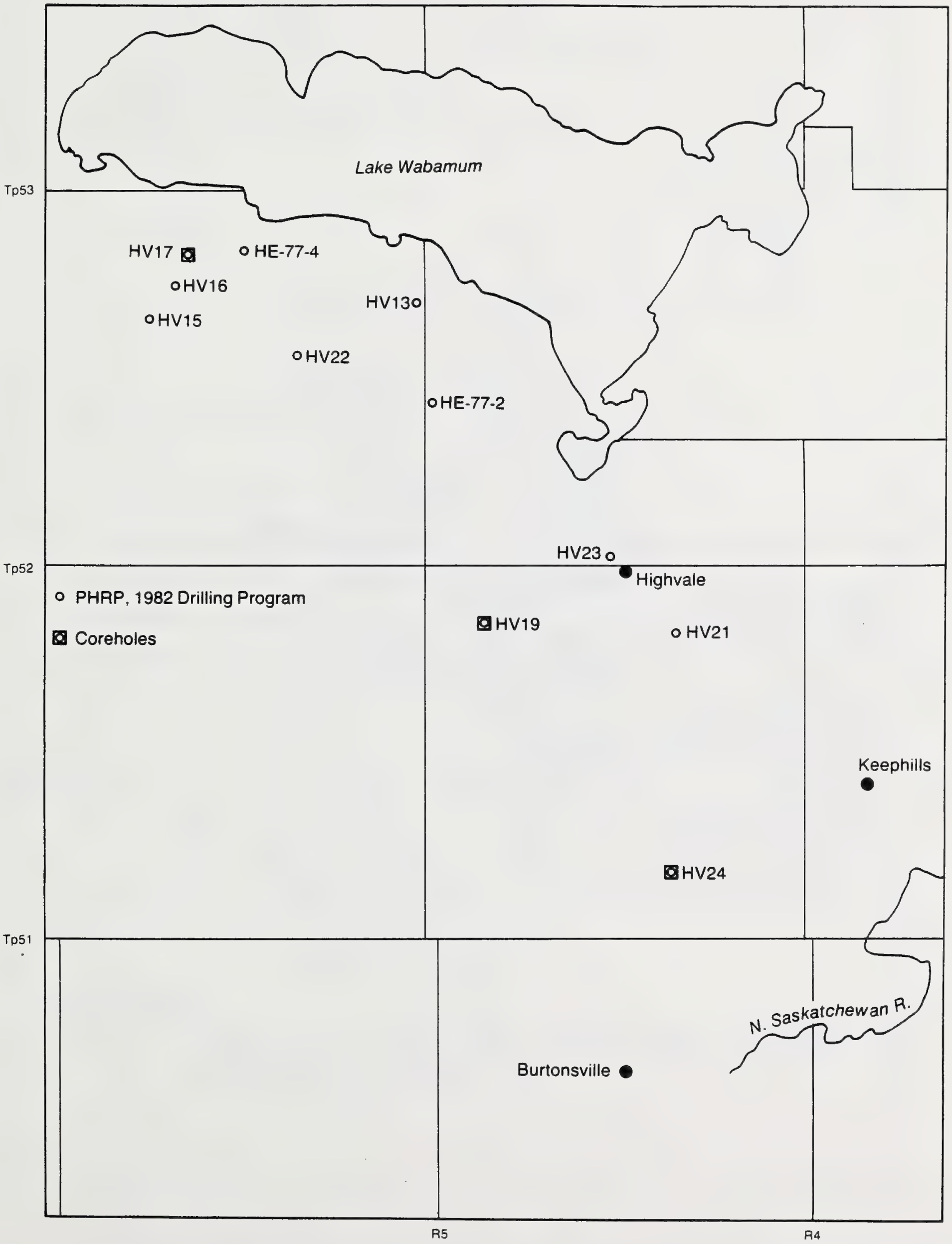

Figure 2. Map showing location of the PHRP boreholes, Highvale study area.

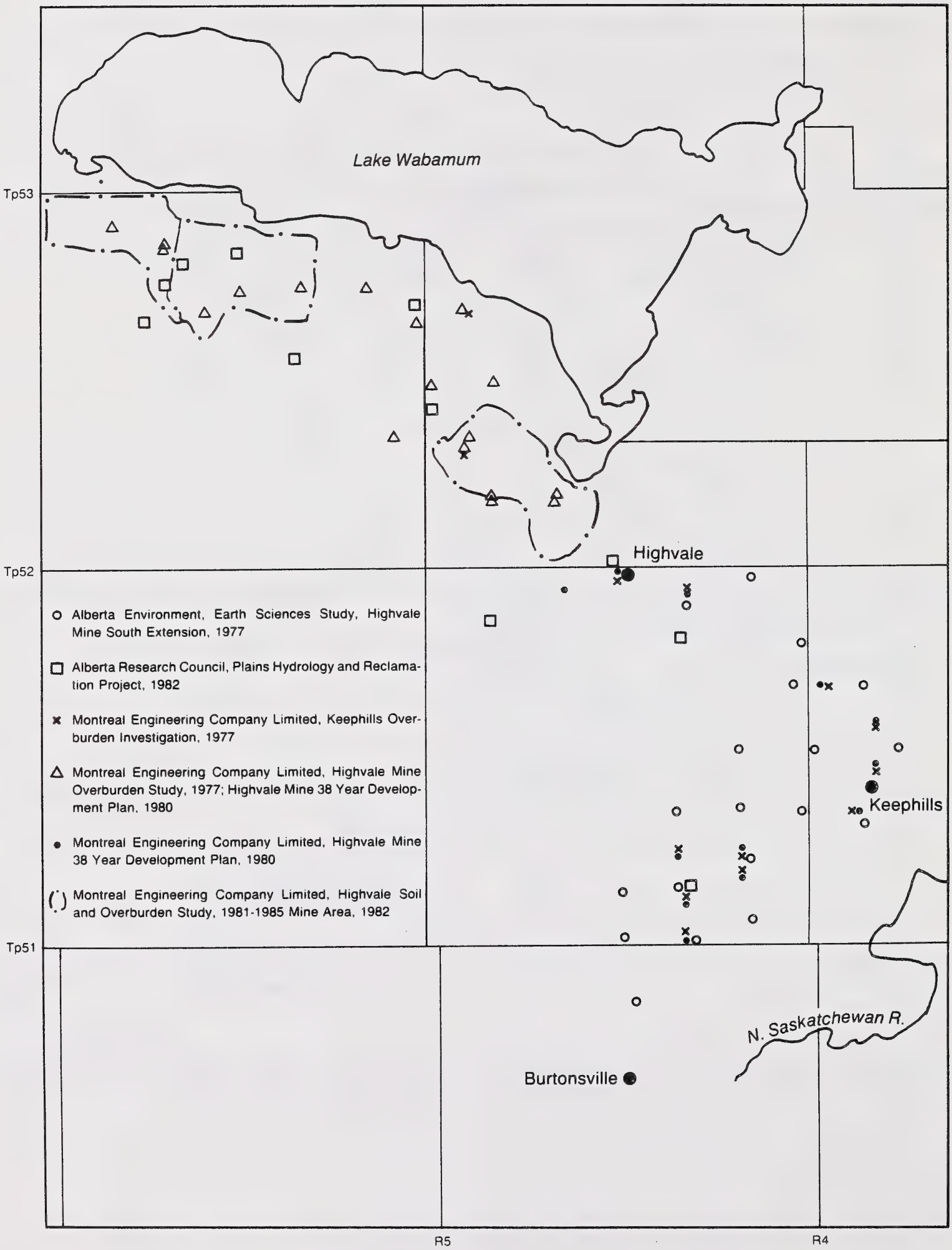
Lake Wabamum
Tp53
Tp52
Tp51
Highvale
Keephills
Burtonsville
N. Saskatchewan R.
R5
R4
○ Alberta Environment, Earth Sciences Study, Highvale Mine South Extension, 1977
□ Alberta Research Council, Plains Hydrology and Reclamation Project, 1982
× Montreal Engineering Company Limited, Keephills Overburden Investigation, 1977
△ Montreal Engineering Company Limited, Highvale Mine Overburden Study, 1977; Highvale Mine 38 Year Development Plan, 1980
• Montreal Engineering Company Limited, Highvale Mine 38 Year Development Plan, 1980
( ) Montreal Engineering Company Limited, Highvale Soil and Overburden Study, 1981-1985 Mine Area, 1982

Figure 3. Map showing location of boreholes and study sites of research programs, Highvale study area, contributing to the present study.

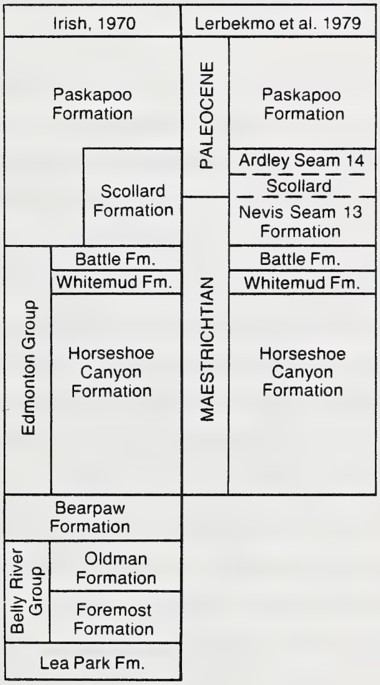

Figure 4. Table of Upper Cretaceous and Tertiary Formations in west-central Alberta.

2. SUMMARY OF THE STRATIGRAPHY AND NOMENCLATURE OF UPPER CRETACEOUS AND LOWER PALEOCENE STRATA IN CENTRAL ALBERTA

The bedrock geology of the Wabamun Lake area consists of Upper Cretaceous and Paleocene nonmarine strata that host several prominent coal seams. This study centres around sediments associated with the Ardley Coal Zone which is presently being exploited in the area.

Much confusion centres around the upper boundary of the Edmonton Formation or the Edmonton Group. Prior to 1970 the contact between the Edmonton Formation and the Paskapoo Formation was delineated by the base of the thick, cliff-forming, yellow-brown weathering sandstone above the coal-bearing horizon called the "Lower Ardley". Irish (1970) felt that, because the sandstone marker horizon above the Ardley Coal Zone was difficult to recognize on a regional basis, it was appropriate to move the Paskapoo Formation boundary down and include the Scollard as a member of that formation. He defined the Scollard Member as that stratigraphic interval "between the Battle Formation and the uppermost coal seam of the coaly zone (so called Ardley Coal Zone)" and redefined the Edmonton Formation elevating it to group status and placed the upper contact of the group at the top of the Battle Formation.

Gibson (1977) felt that the identification of the "upper coal seam" of the Ardley Coal Zone is somewhat tenuous at some localities, therefore, it would be best to discontinue using the "upper coal seam" as the upper contact of the Scollard Member. He proposed that the top of the Scollard Member be reinstated as the base of the massive, cliff-forming sandstone or, in subsurface, the base of the first prominent thick sandstone unit above the uppermost major coal seam of the Ardley Coal Zone.

Allan and Sanderson (1945) suggested that the contact between the Scollard and the overlying Paskapoo Formation was disconformable. Campbell (1962) and Gibson (1977), however, found no convincing evidence to support the existence of a disconformity between these two units. In south-central Alberta in the area between the Bow and Oldman Rivers, beds resembling the Paskapoo Formation rest on beds in the Horseshoe Canyon Formation that are older than the Whitemud and Battle River Formations. Farther to the west, these two formations are present in the subsurface (Irish and Havard 1968) and on this basis, Ower (1958, 1960) and Irish (1970) suggested the possibility of a progressive beveling of the uppermost Cretaceous strata from west to east and from north to south.

Lerbekmo et al. (1979) placed the Cretaceous-Paleocene boundary at the top of the Nevis Coal Seam (No. 13) in Alberta, on the basis of microfloral change, the dinosaurian extinction and radiometric dating.

Geophysical and core data from the Highvale study area do not lend themselves to the nomenclature of Allan and Sanderson (1945), Ower (1958, 1960), Campbell (1967), and Gibson (1977). It is not possible, from the data obtained in this study, to demarcate the first prominent thick sandstone above the Ardley Coal Zone as the base of the Paskapoo Formation. In the study area, the first sandstone above the coal is interpreted as a channel sand, which appears to trend in approximately a NW-SE direction, and is the lateral facies equivalent of overbank deposits encountered in adjacent boreholes at the same stratigraphic level. This study, therefore, follows the nomenclature of Irish (1970) in which all bedrock strata above the Battle Formation are treated as Paskapoo Formation. The Scollard Member is designated as all Upper Cretaceous and Tertiary strata between the Battle Formation and the uppermost coal seam of the coaly zone (so called Ardley Coal Zone). The Cretaceous-Paleocene boundary, as proposed by Lerbekmo et al. (1979), falls within the Scollard Member of the Paskapoo Formation.

2.1 THE SCOLLARD MEMBER

The Scollard Member of the Paskapoo Formation of central Alberta hosts several prominent coal seams that, as a unit, have been called the Ardley Coal Zone (Campbell 1967). Correlation of specific coal seams between areas has been difficult due to limited outcrop and borehole data. Consequently, the nomenclature and correlations that appear in the literature are many and varied.

The two main coal horizons of the Scollard Member are Seam No. 13 and Seam No. 14. In the Red Deer River valley, east of Huxley and Trochu, the No. 13 or Nevis Seam lies between 36.4 and 46.6 m above the base of the Scollard Member (Gibson 1977). At Ardley, Campbell (1967) recorded approximately 22.9 to 24.4 m of strata between the Battle and the 'Ardley' or 'Big Seam' of Allan and Sanderson (1945). Ower (1960) reported 19.8 m for this interval and referred to the seam as the "Lower Ardley".

In the Huxley-Trochu area, Seam No. 14 occurs between 15.2 and 17.8 m above Seam No. 13. Allan and Sanderson (1945) correlate Seam No. 14 at Huxley with the Ardley or Big Seam at Ardley. Gibson (1977), however, points out that the stratigraphic interval between Seam No. 13 and the base of the Scollard Formation decreases in thickness from Huxley toward the north and if this trend continues as far north as Ardley then, accepting the measurements of Ower (1960) and Campbell (1967), the Ardley or Big Seam at Ardley would correlate with Seam No. 13 of the Huxley-Trochu area. Alternatively, if this thinning trend does not continue and the Ardley Seam at Ardley does indeed lie between 19.8 and 24.4 m above the base of the Scollard, then the Ardley Seam at Ardley would probably represent a seam older than either No. 13 or No. 14 (Gibson 1977).

Allan and Sanderson (1945) and Ower (1960) correlate the Ardley or Big Seam at Ardley with the coal zone in the Wabamun Lake area. Holter et al. (1975) suggest that the coal zone in the Wabamun Lake area represents the merging of the No. 13 and No. 14 coal seams of the Red Deer valley area which they designate the "Lower Ardley A" and "Lower Ardley B".

3. GEOLOGY OF THE STUDY AREA

In the western part of the study area, the Paskapoo Formation measures as much as 130 m thick (5-52-5W5), however, the formation is considerably thinner in the proposed mining areas of Highvale and Burtonsville. The contact between the Paskapoo and Battle Formations is encountered at depths between 44.6 and 74.8 m in four boreholes in the study area (Figure 5). The thickness of the Battle Formation in the study area varies between 4.8 and 9.8 m.

In the study area, the Scollard Member of the Paskapoo Formation varies in thickness between 22.7 and 28.2 m with the Ardley Coal Zone 18.8 m above the base. The coal zone is as much as 15.2 m thick and consists of six distinct and laterally continuous seams separated by shale and bentonite partings, which generally comprise less than 30 percent of the coal zone (Figure 6). As much as 11 m of coal is present within the coal zone (Figure 7). The two uppermost seams (1 and 2) are thickest, measuring as much as 3.9 and 3.8 m respectively. In places, Seam 1 is much thinner as a result of removal by fluvial channels; in other places it has been partially or totally removed by glacial erosion. Seams 3, 4, 5, and 6 vary in thickness between 0.4 and 1.3 m. The coal-bearing interval dips southwest at 6 to 8 m per km (Figure 8). Seams 1 and 2 are of major economic interest; Seams 3, 4, and 6, though much thinner, will also be mined. Seam 5 is very shaly and will not be recovered (Monenco, Five Year Mine Plan 1982).

The Paskapoo Formation above the Scollard Member varies in thickness between 0 and 58 m within the study area. North of Highway 627 and to the west-southwest of the proposed mining area (5-52-5W5), the thickness of the Paskapoo Formation above the Scollard Member increases to 96 m. The thickness of overburden materials (bedrock and glacial drift) within the study area varies between 0 and 80 m (Figure 9); the average thickness of overburden materials is 26.2 m.

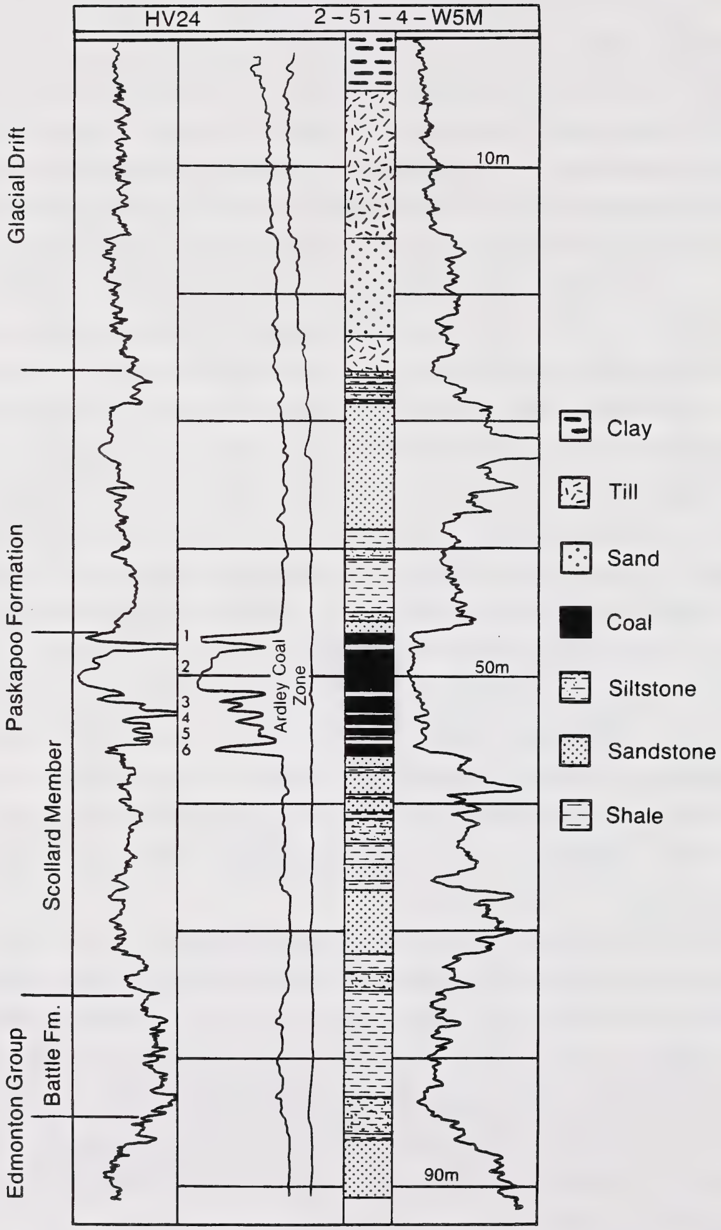

Figure 5. Geophysical log showing general lithology and stratigraphic units encountered, Highvale study area.

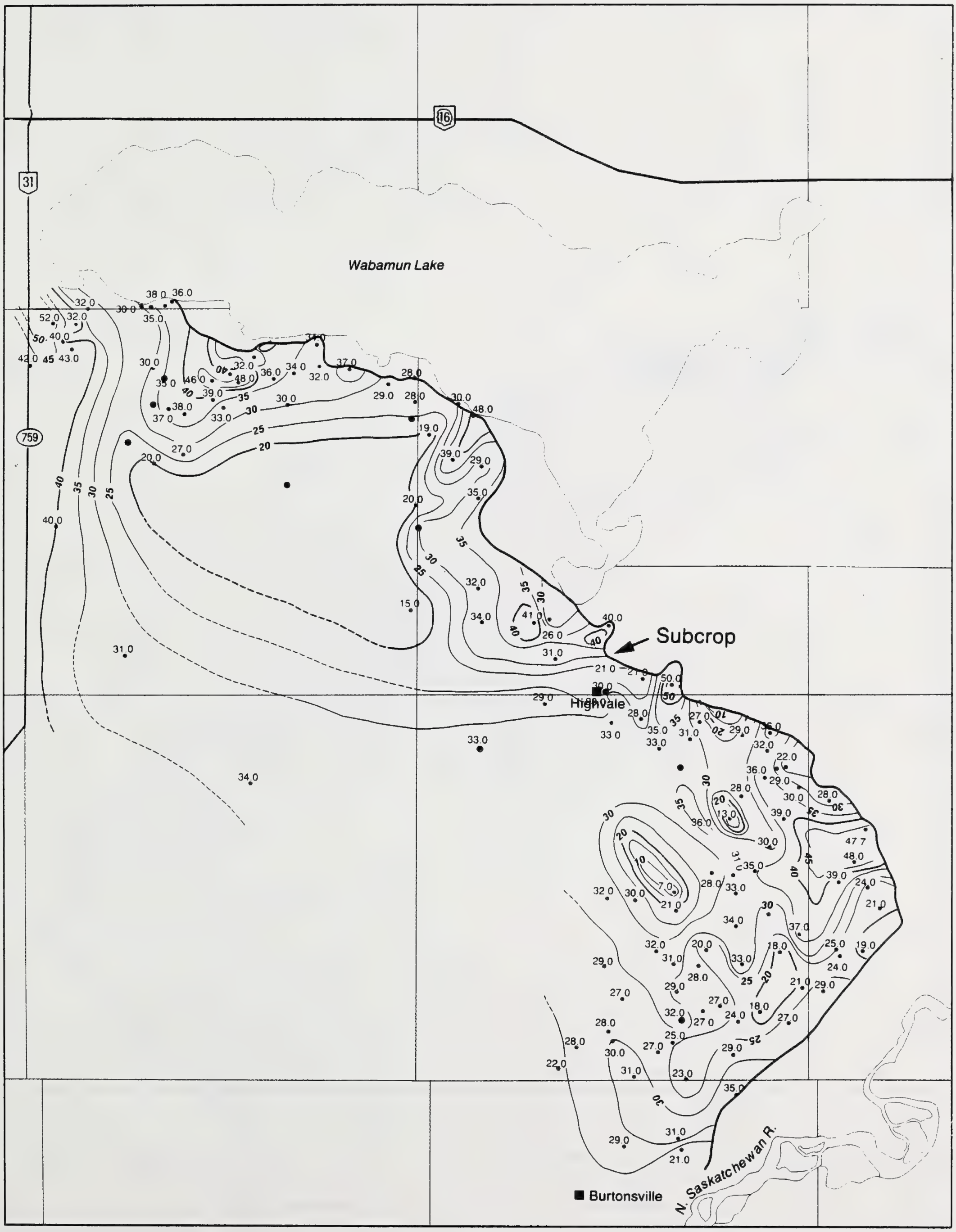

Figure 6. Map showing the percentage of partings within the Ardley Coal Zone, Highvale study area.

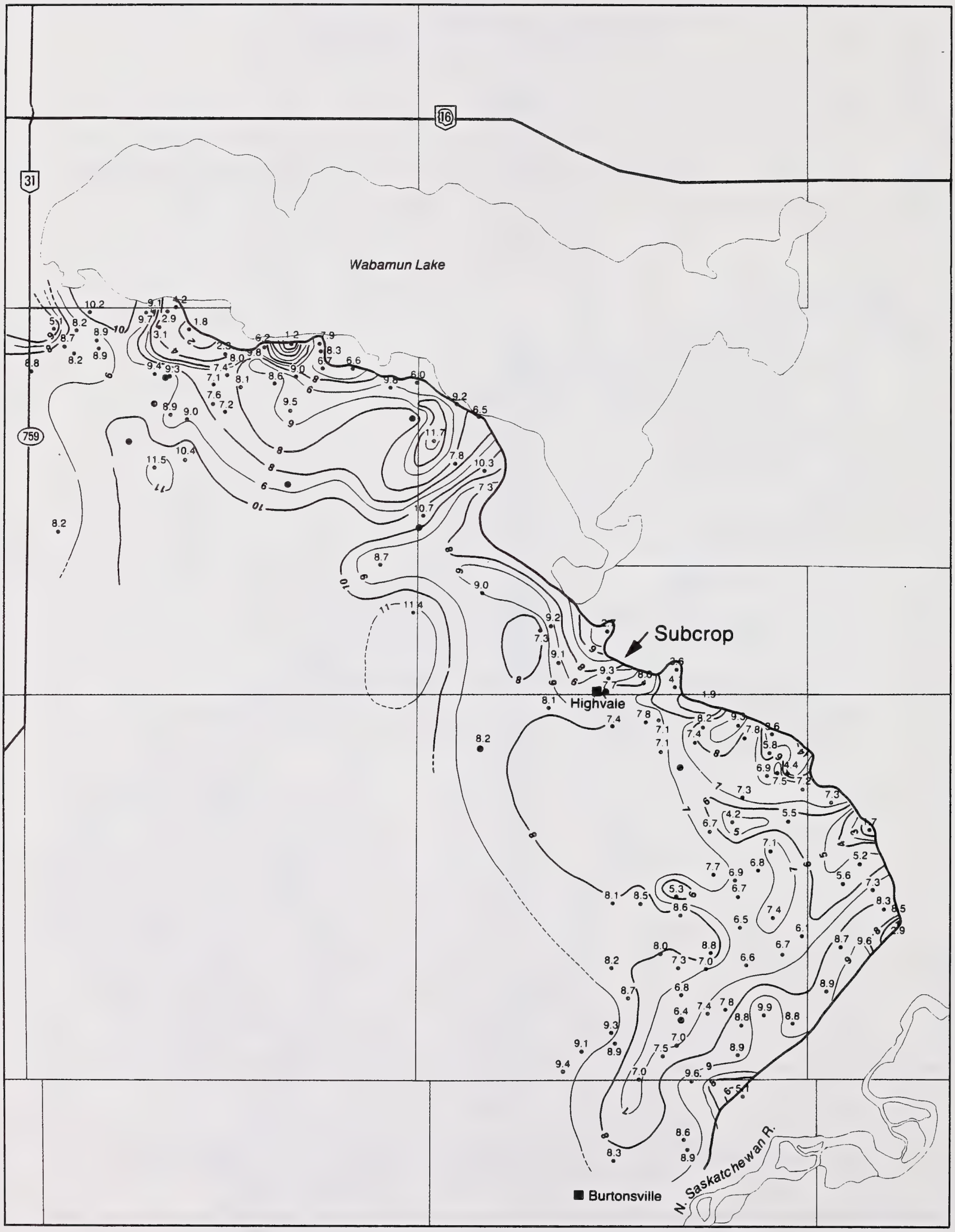

Figure 7. Map showing the total thickness of coal within the Ardley Coal Zone, Highvale study area.

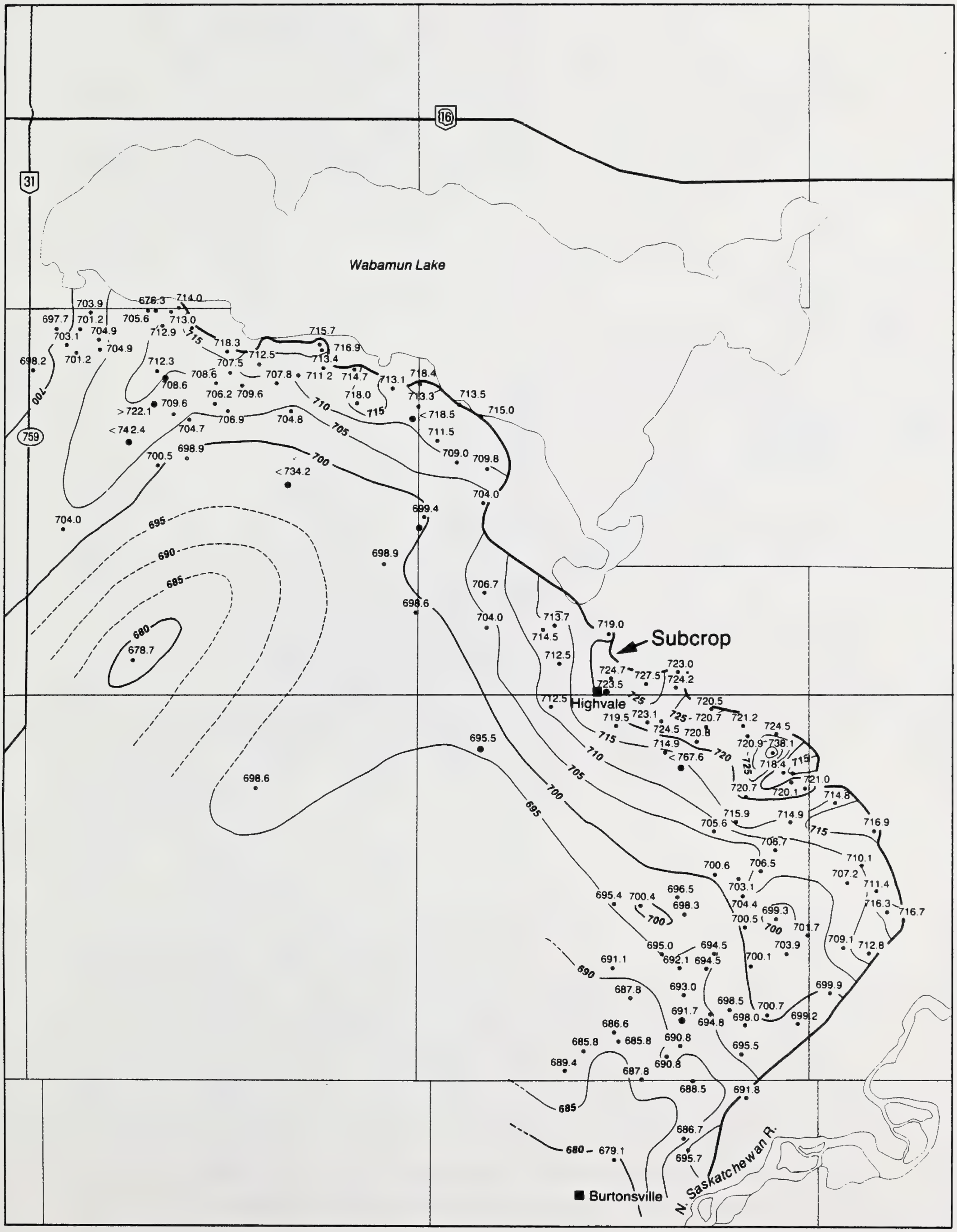

Figure 8. Structural contour map of base of Ardley Coal Zone, Highvale study area.

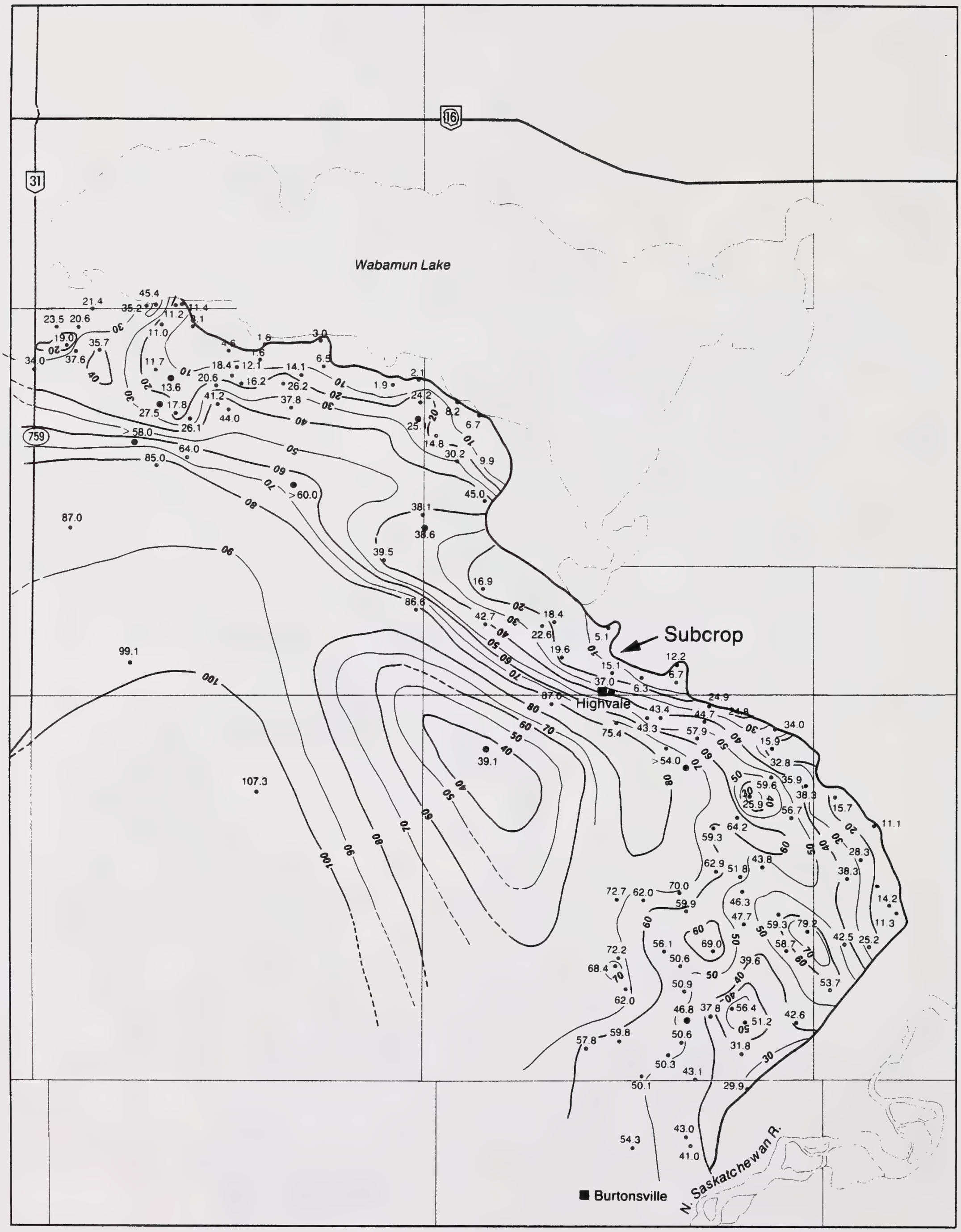

Figure 9. Map showing the thickness of overburden material including both bedrock and drift, Highvale study area.

4. STRATIGRAPHY OF THE OVERBURDEN

In order to characterize the overburden above the Scollard Member in the study area, approximately 160 geophysical logs were examined and geological cross sections through the area were constructed. The Paskapoo Formation above the Ardley Coal Zone in the study area was divided into five gross lithostratigraphic units (Figure 10). The thickness of individual lithologic units varies between localities within the study area as a result of abrupt facies changes, and also possibly due to preferential erosion and beveling by fluvial systems.

4.1 UNIT A

The lowermost unit within the overburden at Highvale is designated Unit A (Figure 10) and is informally called the "Roof Shale". It directly overlies coal seam 1 and varies in thickness between 0 and 13 m. This shale unit is absent at some localities and is replaced by siltstone or sandstone of Unit B that rests directly on the coal. In some boreholes the Roof Shale is interrupted by lenses of sandstone or siltstone that are as much as a few metres thick. The fine-grained portion of Unit A generally consists of dark grey to black, bentonitic, silty shale or mudstone. A layer of bentonite about 5 cm thick directly overlies the coal in many boreholes.

4.2 UNIT B

The next gross lithostratigraphic unit within the overburden is the "Major Sandstone" or Unit B (Figure 10). This unit is as much as 36 m thick, but averages about 20 m thick within the study area. Unit B is predominantly composed of medium grey, fine- to medium-grained sandstone and siltstone. Minor dark grey shale interbeds and laminae occur within the unit. In the vicinity of Burtonsville, however, a significant shaly interval between 14 and 22 m above the coal zone is developed within Unit B. Burrows of _Anchorichnus_ and _Meunsteria_ have been identified (Pemberton 1984,

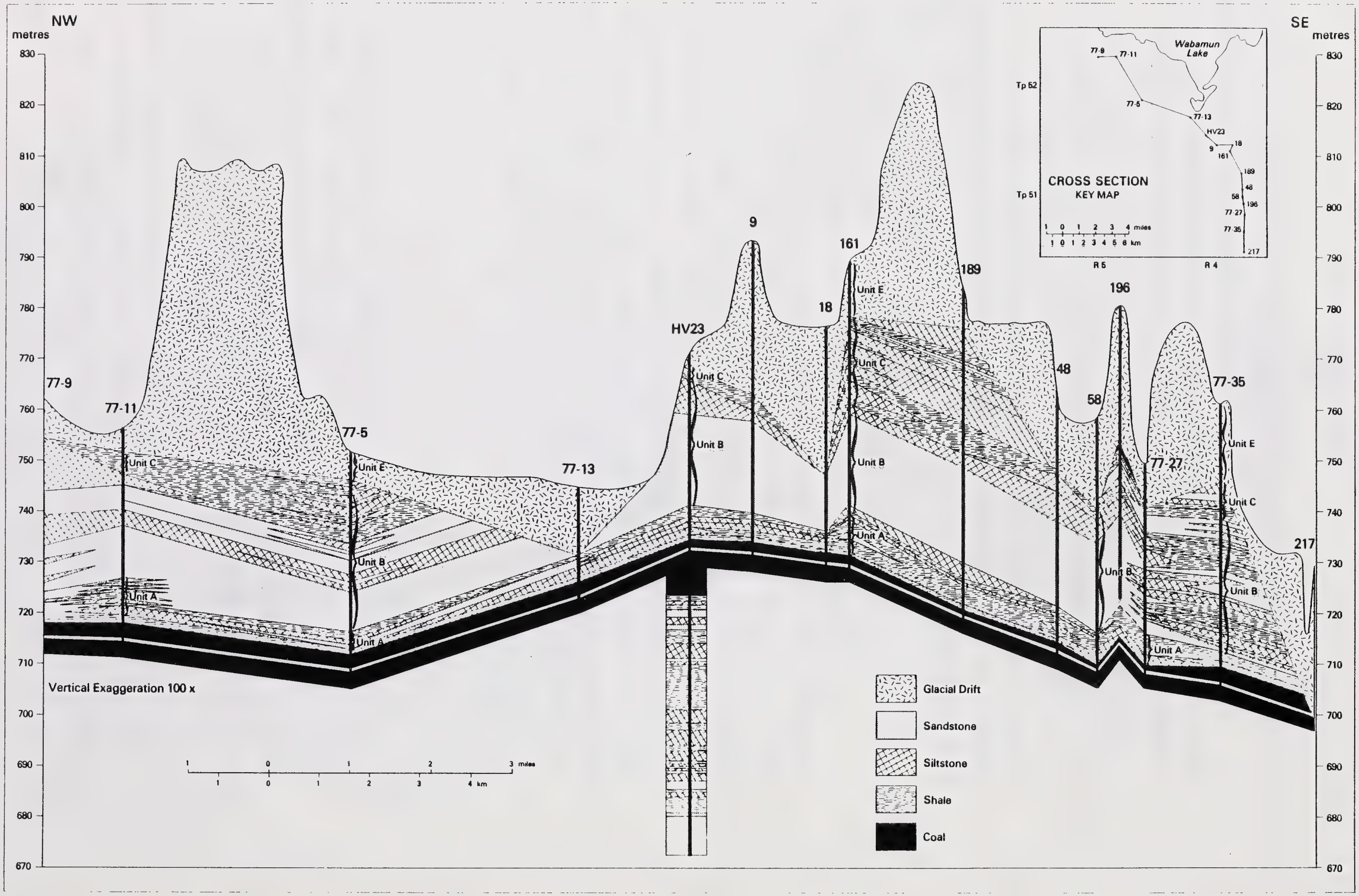

Figure 10. Northwest-southeast stratigraphic cross section through the Highvale study area.

personal communication) in shale and siltstone beds of Unit B, which are indicative of a moist floodplain environment. Geophysical logs show that Unit B is generally thicker and consists of better developed, stacked sandstone bodies in the southeastern part of the study area. Lateral facies changes result in the intertonguing of siltstone and shale with sandstone through much of the unit in several places in the study area. In some boreholes the contact between Unit B and the underlying shale of Unit A is sharp and abrupt, whereas in other places it is gradational and the shale of Unit A grades upward into, or is interdigitated with siltstone and sandstone of Unit B.

The sandstone of Unit B is generally medium bedded with low-angle cross stratification and thinly bedded with ripple marks, which are, in places, draped with clay. Diffuse horizontal and subhorizontal laminae are recognized in many of the thicker sandstone beds. Complete fining upward sequences are observed in core HV19 (32-51-4-W5M). Such sequences begin with a scoured base overlain by medium-grained, cross-bedded sandstone that grades upward through fine-grained, planar-bedded, and laminated sandstone and siltstone into mudstone with bedding that is disturbed by bioturbation. The thickness of these sequences is generally less than 15 cm, and it is thought that they may represent small crevasse splays in the overbank environment.

Numerous concretionary bands occur within Unit B. These bands are traceable over pit highwall exposures, however, locally they pinch and swell, disappearing altogether in places. The concretionary bands are not restricted to a particular lithology; they occur parallel to bedding planes in sandstone, siltstone, and shale. The mineralogy of these concretionary bands, as determined by x-ray diffraction analysis, is primarily siderite, but quartz, dolomite, calcite, feldspar, and clay minerals were also detected. Correlation of stratigraphic units on the basis of these concretionary bands in the subsurface should be approached with caution because of the pinch and swell character of the bands.

4.3 UNIT C

The third lithostratigraphic unit above the coal, Unit C (Figure 10), is as much as 28 m thick and consists primarily of interbedded and interlaminated dark grey shale, dark grey to green-grey mudstone, and medium-grey siltstone with minor beds or lenses of sandstone. The boundary between Unit B and Unit C is generally difficult to determine, but it is best drawn at the top of the uppermost significant sandstone, above which the sequence is dominated by shale, mudstone, and siltstone.

4.4 UNIT D

At a few sites within the study area, a much greater thickness of overburden is encountered. These sites are topographically higher than the surrounding area. The upper portion of the overburden at these sites is designated Unit D and may consist of undisturbed bedrock or it may be blocks of disturbed and possibly displaced bedrock. Geophysical logs from boreholes A71 (18-52-5W5), B14 (5-52-5W5), and A65 (27-51-5W5), and geophysical logs and chip samples from boreholes HV15 (20-52-5W5), HV21 (26-51-4W5), and HV22 (23-52-5W5) suggest that the bedrock sequence is intact and is simply thicker as a result of absence of glacial erosion. However, the geophysical logs from a few boreholes, for example HV6 (NW-23-51-4W5), suggest repetition of section. A detailed study of glacial disturbance at the Highvale Mine is being conducted by the Alberta Research Council under contract to TransAlta Utilities (Fenton et al. 1983).

Unit D varies in thickness between 6 and 14 m within the study area. It is composed dominantly of medium to dark grey, fine-grained sandstone with a salt and pepper aspect interbedded with medium grey siltstone and lesser amounts of medium to dark grey and green-grey shale.

4.5 UNIT E

Unit E, the glacial drift, consists of glacial till, clay, and blocks of disturbed bedrock. The thickness of this unit varies between 1.0 and 43.1 m (Figure 11). In the northern part of the study area (north of Highway 627) the drift is generally thin and varies in thickness between 1.0 and 18.8 m, averaging 6.8 m thick. In the southern part of the study area (Keephills, Burtonsville) the drift is generally much thicker than in the north, however, it thickens and thins abruptly and markedly over the area. In the south, the drift varies in thickness between 1.2 and 43.1 m, averaging 18.1 m thick. The contact between drift and bedrock is difficult to pick from geophysical logs alone and, therefore, the thickness of drift reported here is only an estimate. The lower portion of the glacial deposits in the three coreholes studied is dominated by clayey till. This till is medium grey to very dark grey and contains abundant small shale fragments, oxidized sandstone clasts, small (1 to 2 cm) rounded pebbles, and coal fragments. At site HV24 (2-51-4-W5M), unconsolidated sand was encountered in the lower glacial deposits at 16 and 22 m depths (Figure 5). Yellow brown, silty clay, and till were cored from the upper 2.4 and 4 m of drift in holes HV19 and HV24, respectively. Light to very dark brown, dense clay was encountered in the uppermost 2.4 m of drift at HV17.

Bedrock strata are known to be incorporated within the drift at many localities in the study area (Fenton et al. 1983). This situation is best observed near the subcrop of the coal zone because displaced coal beds can be easily detected on the geophysical logs. The extent to which bedrock strata are incorporated within the drift could not be assessed in this study because of the limited amount of core extracted. Core data from other drilling programs were not examined in detail as part of the present study. In corehole HV19 of the PHRP 1982 drilling program, however, disturbed shale in the form of shale-pebble till was encountered at 7.6 m depth. Disturbed shale in this form suggests bedrock strata have

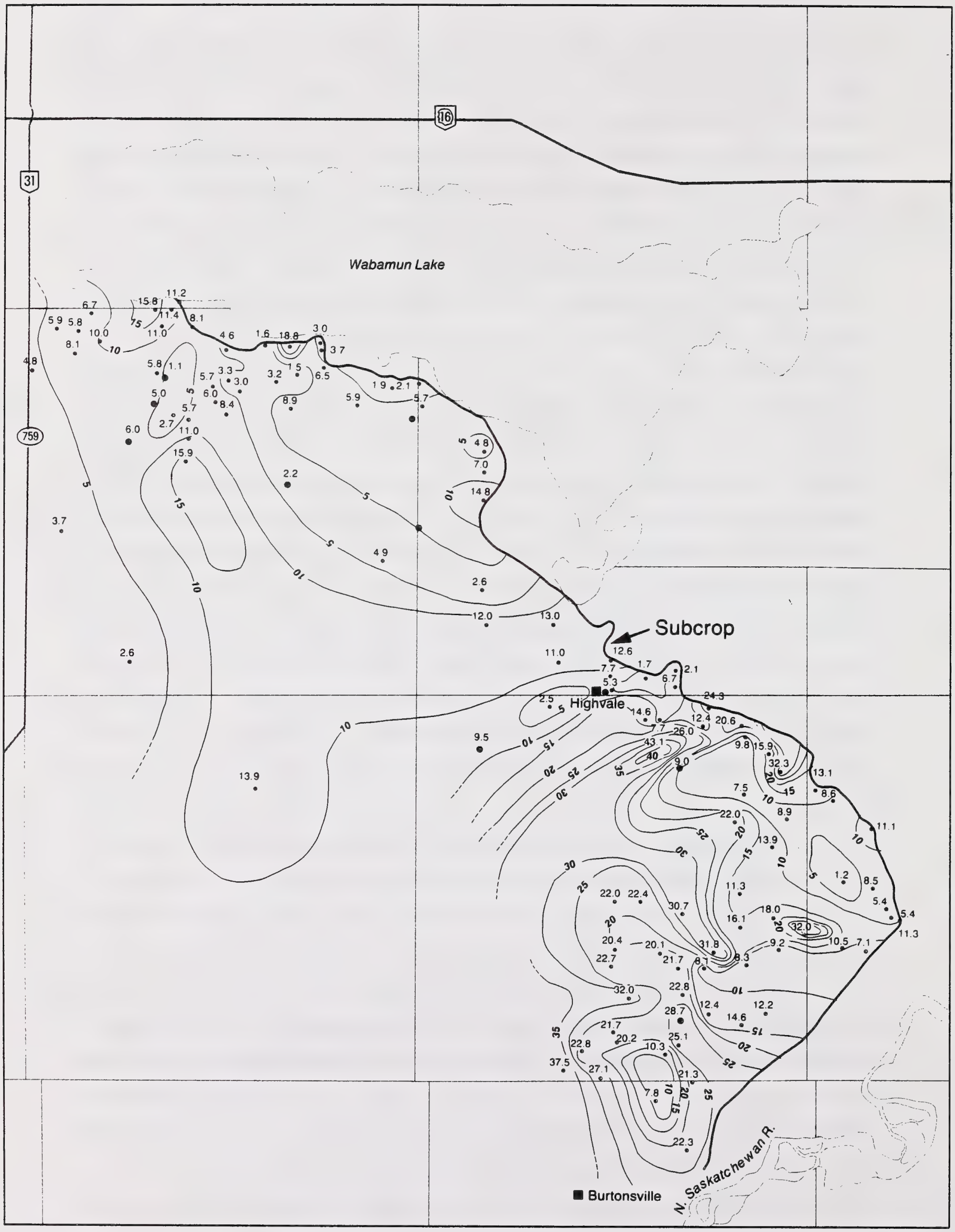

Figure 11. Map showing the thickness of glacial drift, Highvale study area.

been disturbed by glacial processes. It is not known whether this disturbance involves only minor shearing and movement of the uppermost bedrock strata or whether large faults extending deeper into the bedrock can be expected. The structure contour map of the coal zone (Figure 8) indicates that structural disturbances did not extend as deep as the coal zone over most of the site. Several earlier studies have interpreted large blocks of bedrock to be resting within glacial drift. It seems, however, that the data available are inadequate to confirm whether or not these blocks of bedrock are associated with the underlying bedrock strata or whether the blocks have been transported for considerable distances, in which case, inferences regarding the structural state of the underlying bedrock could not directly be made. The degree of disturbance of bedrock to the west and southwest of the coal subcrop, where the thickness of overburden Paskapoo strata is greater, is yet unknown.

5. CORRELATION AND INTERPRETATION OF STRATIGRAPHIC UNITS

As discussed in section 2 above, problems of regional correlation of the coal and overburden sequences within the Ardley Coal Zone in the Wabamun Lake area have long plagued geologists. As more and better quality subsurface data have become available, it has been possible to trace the coal zone itself over wider areas and resolve most of the questions related to the coal itself. Because of the major differences in the overburden lithology from place to place, however, problems persist in understanding stratigraphic relationships within the overburden. In particular, the interval identified as Unit B in the present study poses questions. In the Highvale Study area, unit B is composed of two distinct facies: interfluvial or overbank deposits and channel deposits. Interbedded, fine-grained, argillaceous sandstone, siltstone, and shale, as observed in Pit 2 of the Highvale Mine (Figure 12), are representative of overbank and interfluvial environments. Thick bedded, massive sand units, as identified in boreholes HV13 and HV77-2 (Figure 13), represent major channels within the fluvial system.

At several sites within the study area, the bedrock overburden is dominated by flat-lying, interbedded shale, siltstone, and sandstone (Figure 12). The lowermost shale unit is mapped as Unit A and the overlying beds are mostly mapped as Unit B. The sandstone beds of Unit B at such localities tend to be thin (1 to 5 m) and argillaceous, as determined from logs, core, and chips. At the scale of a few hundred metres, this sediment appears to be stratigraphically continuous. Correlation of geophysical logs and construction of cross sections over larger areas, however, make facies changes evident. In some areas the facies changes over 1 or 2 km are very subtle, whereas, in other areas they are very abrupt.

In the southern part of the study area most geophysical logs show the presence of thick, possibly stacked, sandstone bodies at the level of Unit B in the overburden sediment. Many adjacent logs, however, show thin units of sandstone interbedded with siltstone and shale, a sequence similar to that observed in Pit 2 of

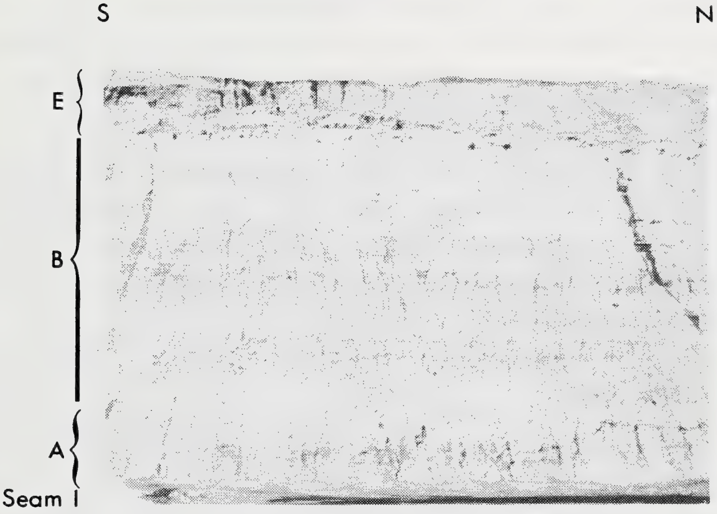

Figure 12. Photograph of Pit 2 highwall, Highvale Mine, showing overburden stratigraphic units A, B, and E.

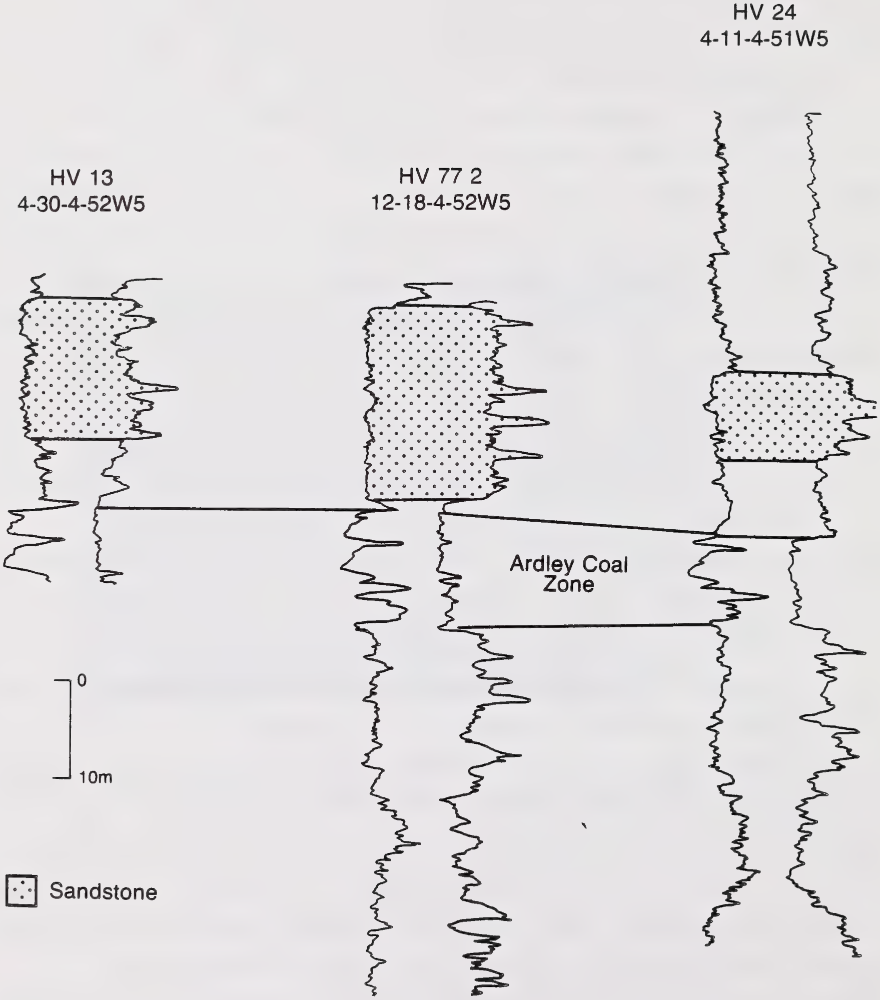

Figure 13. Geophysical logs of boreholes showing the presence of thick sandstone units in the overburden sediment, Highvale study area.

the Highvale Mine. Interpretations of geophysical logs indicate that numerous, abrupt lateral facies changes occur. The interpretation is, therefore, that lithostratigraphic Unit B of the southern part of the study area is dominated by a channel sandstone facies, but lesser amounts of fine-grained overbank sediment also occur. For the entire study area, a complex sequence of laterally equivalent channel and floodplain deposits is interpreted from the logs, cores, and chips (Figure 14). The trend of the major channel through the area appears to have been from northwest to southeast along the eastern margin of the study area.

As one expands the area of concern beyond the Highvale Mine to other mines in the Wabamun Lake area, the situation becomes less clear. At Whitewood Mine, north of Wabamun Lake and Highway 16, a thick, light grey, yellow weathering sandstone unit overlying dark grey shale, which rests on the Ardley Coal Zone, is observed in highwall exposure (Figure 15). This sandstone is significantly different in aspect from the sandstone exposed in the Highvale Mine. A gravel unit, unconsolidated sand unit, and till unit successively overlie the thick sandstone unit (Figure 16). Large-scale trough cross-beds are recognized within the sandstone unit. In the literature, massive sandstone at this stratigraphic level that exhibits blocky jointing, cross-bedding, and yellow weathered colour, has been classified as Paskapoo Sandstone and has been used by some authors to delineate the base of the Paskapoo Formation (Allan and Sanderson 1945).

Three possible stratigraphic relations exist to account for distribution of sandstone beds in the Wabamun Lake coal field area.

1. On the basis of thickness, massiveness, and stratigraphic position, it is possible that the sandstone at Whitewood Mine is equivalent to the sandstone above the coal at HV13 and HV77-2, and also the thick sandstone beds above the coal in the Keephills area. All these sandstone bodies could be lateral facies equivalents of floodplain deposits recognized at adjacent sites (Figure 14).

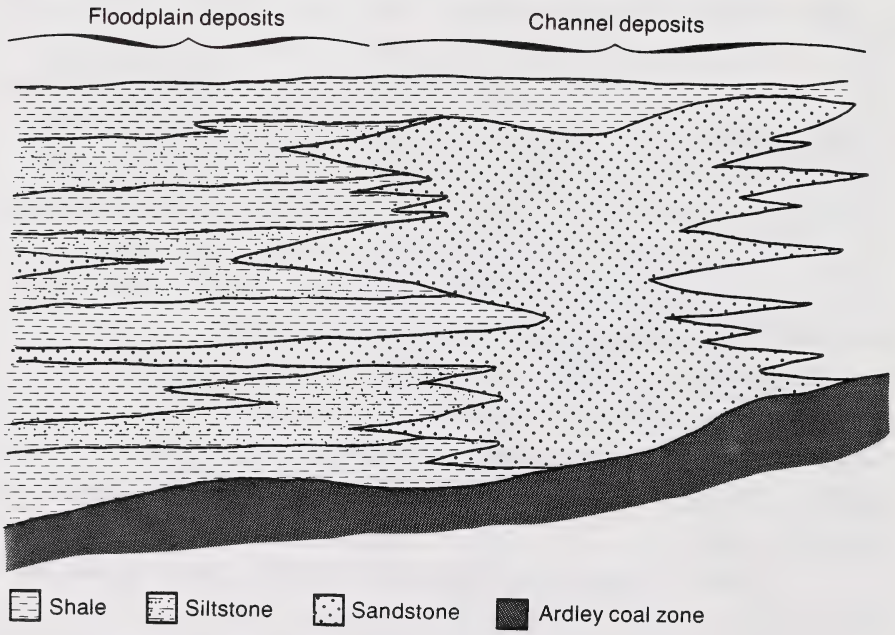

Figure 14. Sketch illustrating the relationship between floodplain and channel deposits, Highvale study area.

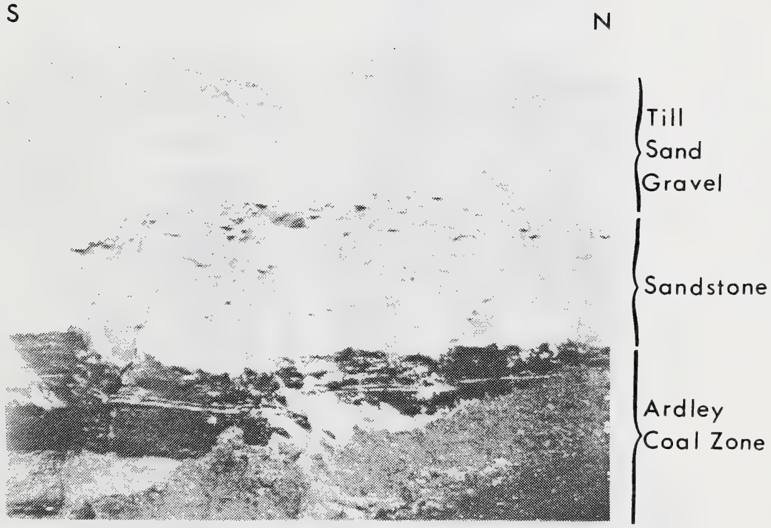

Figure 15. Photograph of highwall in the Whitewood Mine showing massive sandstone unit overlying shale and coal.

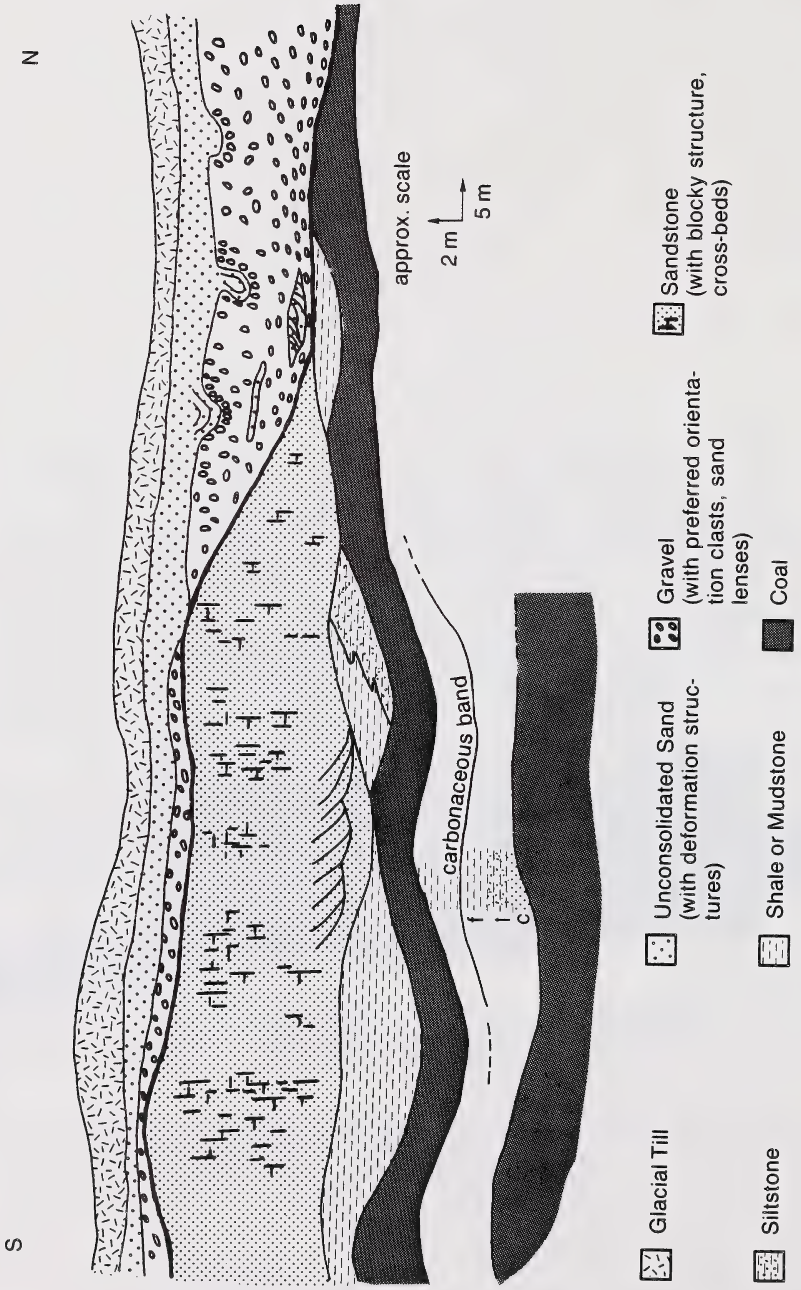
N
S
approx. scale
2 m
5 m
carbonaceous band
c
Glacial Till
Unconsolidated Sand (with deformation structures)
Gravel (with preferred orientation clasts, sand lenses)
Sandstone (with blocky structure, cross-beds)
Siltstone
Shale or Mudstone
Coal

Figure 16. Sketch of highwall exposure in the Whitewood Mine, spring 1983, showing major stratigraphic units and sedimentary features.

2. Alternatively, the sandstone at Whitewood Mine and some or all of the sandstone bodies grouped as lithostratigraphic Unit B at sites such as HV13, HV77-2, and several locations in the Keephills area, could be Paskapoo Sandstone as described by Allan and Sanderson (1945) and Ower (1960). In this case, the base of these sandstone bodies would represent an unconformity and these sandstone bodies would have no genetic relationship to the adjacent floodplain deposits (Figure 17).
3. A third possibility is that the thick sandstone bodies depicted in the logs from Highvale and Keephills, delineated in this study as Unit B, are actually composite sandstone bodies composed of (a) channel sandstone bodies that are the facies equivalents of adjacent floodplain deposits, and (b) unconformable sandstone bodies significantly younger than the adjacent floodplain deposits (Figure 17).

Evidence presently available does not allow resolution of these three possibilities.

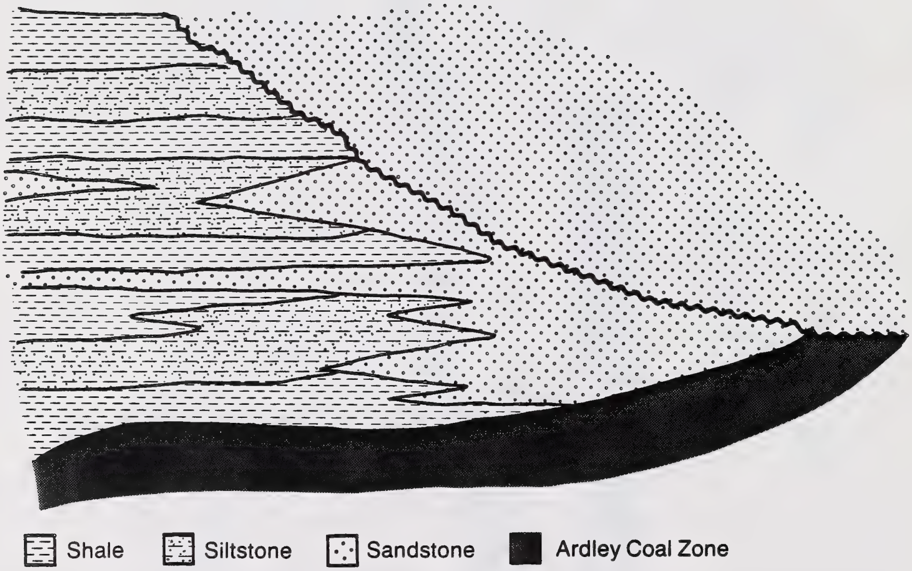

Figure 17. Sketch illustrating the possible relationships between thick sandstone bodies and finer-grained sediment in and near the Highvale study area.

6. SCOLLARD MEMBER BELOW THE ARDLEY COAL ZONE

The Scollard Member below the coal zone was examined to determine whether sandstone beds were present beneath the base of mining that might serve as aquifers to replace those lost during the mining process. Thin section studies and scanning electron microscopy were undertaken to determine the mineralogy, clay content, and type and porosity of the sandstone. Grain size and carbonate analyses were also performed.

Geophysical logs show the lithology below the Ardley Coal Zone to be highly variable within the study area. One or two prominent sandstone beds between the Battle Formation and Ardley Coal Zone are identified at several localities, but these sandstone lenses are not stratigraphically continuous throughout the study area. Where identified, the sandstone lenses are 1 to 4 m thick, fine to coarse grained, and are interbedded with siltstone and minor shale. At some localities, beds within the sandstone lenses are very well cemented and indurated, whereas, at other places they are friable. The sandstone lenses vary from very calcareous to only slightly calcareous.

The sandstone at 53.5 m in corehole HV19 (32-51-4-W4M) is very fine-grained, medium grey, poorly sorted, and has a salt and pepper aspect. The framework consists of fragments of angular chert, subangular potassium feldspar and plagioclase and subangular fragments of volcanic rock (Figure 18). Large flakes of detrital muscovite and chlorite are present (Figure 19). Abundant hematite is present as interstitial grains. The matrix is primarily made up of clay minerals and secondary silica. The clay mineralogy of the sandstone, as determined by x-ray diffraction of the <2)m fraction, includes 88 percent smectite, 9 percent kaolinite, 2 percent illite, and 1 percent chlorite. Observation of the sandstone with the scanning electron microscope shows that the smectite occurs as thick coatings on detrital grains and as pore bridges (Figure 20). Carbonate cement occurs sparsely and unevenly throughout the sandstone. The carbonate equivalent, as determined by the

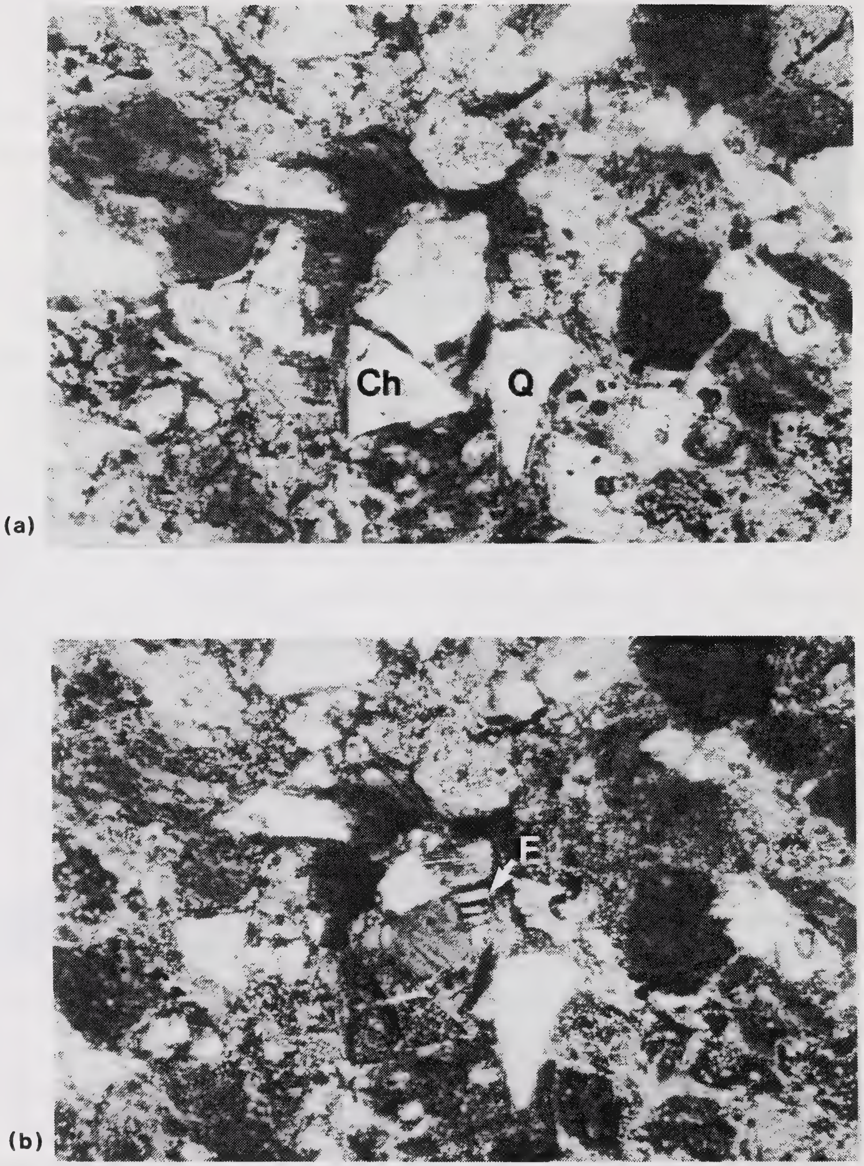

Figure 18. Photomicrograph of sandstone in the Scollard Member below the coal zone at HV19 (53.5 m), (a) plane polarized light, (b) cross-polarized light. Mag 10X.

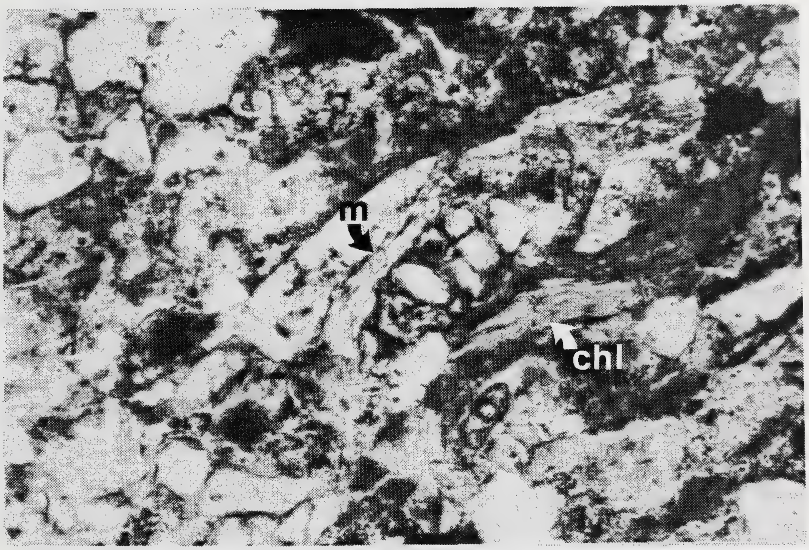

Figure 19. Photomicrograph of sandstone in the Scollard Member below the coal zone at HV19 (53.5 m) showing large detrital muscovite (m) and chlorite (chl) flakes.

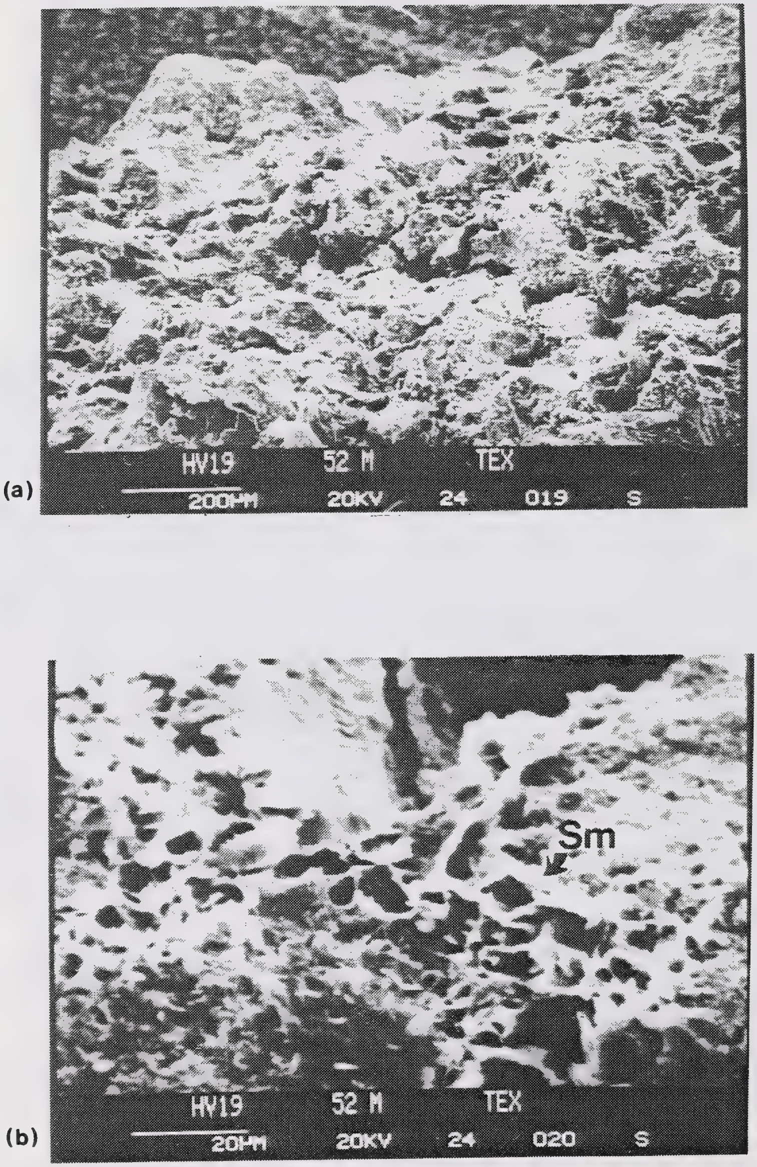

Figure 20. Scanning electron micrograph of sandstone in the Scollard Member below the coal zone at HV19, (a) texture of sandstone showing abundant argillaceous matrix, (b) thick grain coats and pore bridges of smectite (sm).

gravimetric method, is 1.7 weight percent of the sandstone. The porosity is estimated to be a few percent.

The sandstone at 67 m in corehole HV24 (2-51-4-W5M) is medium-grained, medium grey, poorly to moderately sorted, and exhibits a salt and pepper aspect. The framework includes angular to subrounded grains of quartz, feldspar, chert, volcanic, and sedimentary rock fragments, and minor polycrystalline quartz (Figure 21). Flakes of detrital muscovite and chlorite occur between and around the framework grains. Small, irregular masses of hematite occur within intergranular spaces and appear to be most commonly associated with chert and volcanic rock fragments. Recrystallization along grain boundaries of chert fragments is relatively common within the sandstone. The matrix and cement of the sandstone are difficult to differentiate in thin section since the matrix is predominantly composed of very fine-grained clay minerals that have altered from originally deposited volcanic glass. Smaller amounts of authigenic feldspar (Figure 22) and carbonate minerals were also observed with the scanning electron microscope. The clay mineralogy, as determined by x-ray diffraction, is 96 percent smectite (Figure 22) and 4 percent kaolinite. The gravimetric method of analysis indicates that the sandstone contains 2.4 weight percent carbonate. Appreciable carbonate cement is recognized in thin section. The porosity is estimated to be 2 to 5 percent, but it is very localized. The permeability of this sandstone can be expected to be very low due to the low porosity and abundance of smectite. Sandstone at 71 m in this corehole has the same mineralogical framework as the sandstone described above, however, it has a medium- to coarse-grained texture, abundant fine- and coarse-grained carbonate cement (Figure 23), less hematite, and as much as 10 percent porosity in places.

Grain size analyses of samples below the coal zone in coreholes HV19 and HV24 classify this sediment as predominantly silt (<63μm) (63 and 61 percent, respectively) and sand (>63μm) (22 and 29 percent, respectively). The clay fraction (<4μm) makes up only 15 percent of the sediment below the coal at HV17 and 11 percent at

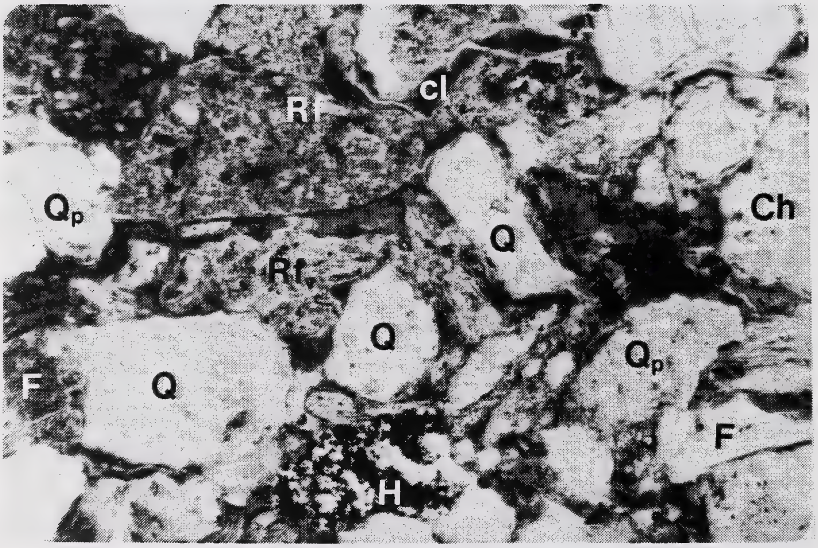

Figure 21. Photomicrograph of sandstone in the Scollard Member below the coal zone at HV24 (67 m) showing its mineralogy and texture.

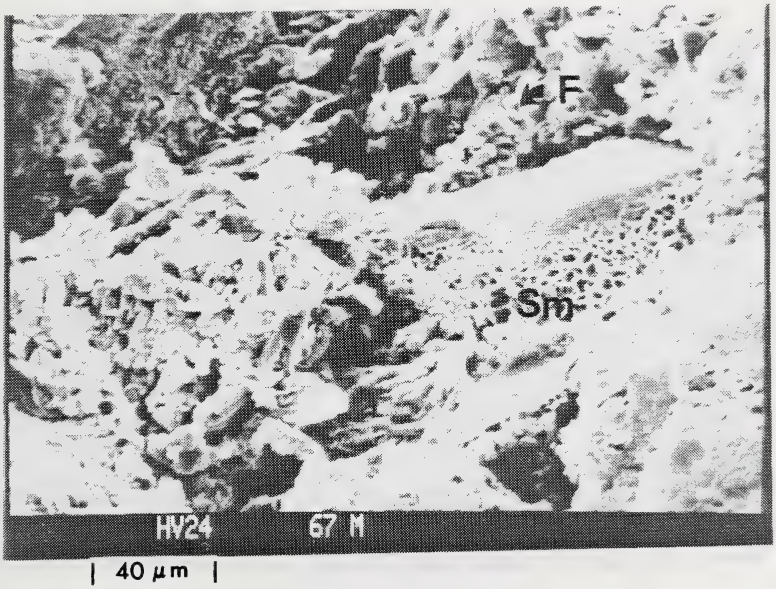

Figure 22. Scanning electron micrograph of sandstone in the Scollard Member below the coal zone at HV24 showing abundant authigenic minerals in the matrix including smectite (sm) and feldspar (f).

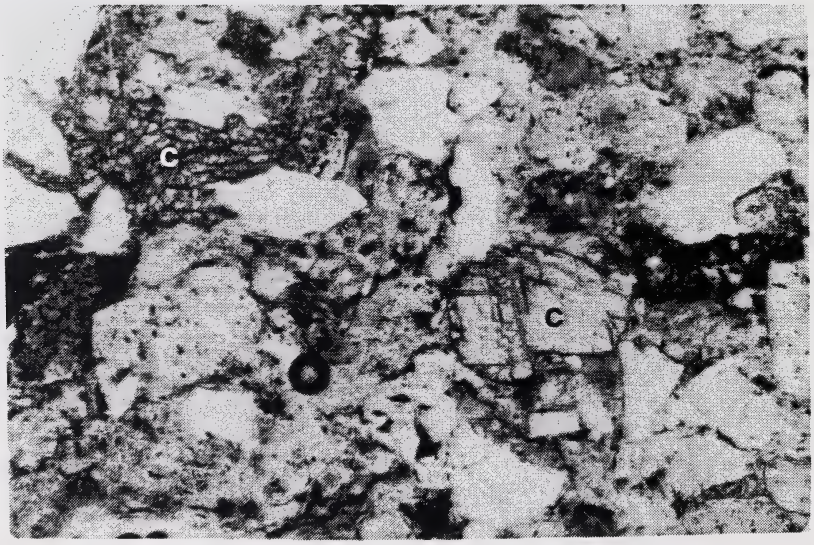

Figure 23. Photomicrograph of sandstone in the Scollard Member below the coal zone at HV24 (71 m).

HV24. The few shale beds that occur within this interval in the study area are very silty.

7. SUMMARY OF STRATIGRAPHY AND GEOLOGY IN THE STUDY AREA

In summary, the bedrock overburden at the Highvale Study area consists of continental sediment of the Paskapoo Formation which was deposited in fluvial channels, floodplains, and interfluvial areas. Above the Ardley Coal Zone, which is lower Paleocence in age, five lithostratigraphic units have been delineated. Immediately above the coal is dark grey shale of Unit A. This unit represents deposition within a very low energy environment such as a floodplain or lacustrine environment. Overlying Unit A are interbedded sandstone, siltstone, and shale sequences or thick sandstone beds of Unit B. Unit B represents major channel deposits and overbank or interfluvial deposits. Unit C is characterized by a dominance of shale or mudstone and represents a low energy floodplain environment. Lithostratigraphic Unit D consists of salt and pepper, fine-grained sandstone, that occurs beneath topographically high areas within the study area. Unit E is the surficial veneer of glacial clay, silt, till, and blocks of disturbed bedrock; the thickness of this unit is generally greater in the southern part of the study area (Andriashek, personal communication).

8. PHYSICAL, CHEMICAL AND MINERALOGICAL PROPERTIES OF THE OVERBURDEN

As part of the PHRP study, continuous cores from surface through the Ardley Coal Zone were extracted at three sites in the Highvale study area: HV17 (28-52-5W5M), HV19 (32-51-4W5M), and HV24 (2-51-4W5M). These cores were sampled at about 0.5 m intervals or where distinct lithologic changes were observed. Nineteen drift samples and 22 bedrock samples were analyzed for grain size, clay mineralogy, carbonate content, cation exchange characteristics, and soluble ions by means of the saturation paste extract technique. The geologic characterization of the samples, as well as the most important properties of the overburden from the standpoint of reclamation, are discussed in this section. Chemical and physical data from five additional studies of the Highvale area (Figure 2) were collected from published reports and manipulated statistically. The distributions, means, and medians of these data and the PHRP data are listed in Table 1 for pH, EC, saturation percentage and SAR for drift and bedrock samples from the six studies.

8.1 PARTICLE-SIZE ANALYSES

Particle size analyses determined by the hydrometer method indicate that the entire sequence above the coal zone appears to be dominated by the silt-size fraction with individual units being modified by lesser or greater amounts of sand and clay (Figure 24). Unit A of the overburden strata is dominated by silt-size particles (<63μm to 4μm), which comprise an average of 66 percent of the sediment in that unit. Sand (>63μm) and clay (<4μm) particles made up the remaining 22 and 12 percent of the sediment, respectively. These averages were obtained from only three samples and probably reflect sandstone and siltstone lenses present at these localities within Unit A. A larger sampling population would likely show a greater abundance of clay-size particles within this unit. Fifteen samples from Unit B yield means of 26 percent sand, 49 percent silt, and 25 percent clay for this unit. Nineteen samples from Unit E

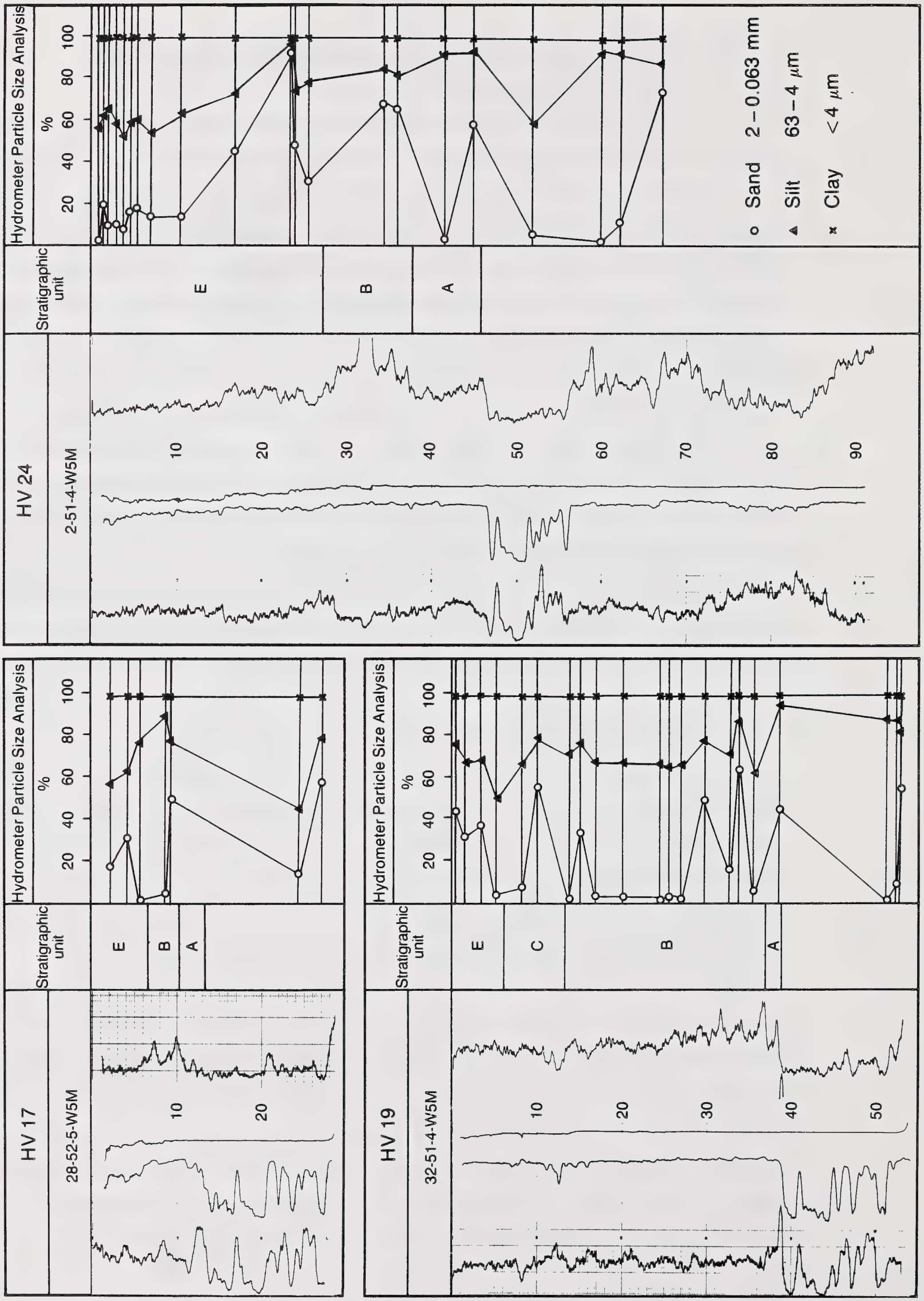

Figure 24. Particle size analyses of bedrock samples from coreholes HV-17, HV-19, and HV-24, Highvale study area.

yield grain size means of 24 percent sand, 40 percent silt, and 36 percent clay.

8.2 CLAY MINERALOGY

The clay mineralogy of the overburden samples was determined by x-ray diffraction of the $<2\ \mu m$ fraction of oriented specimens. The relative percentages of the clay mineral phases were estimated using the peak-height method; first order peaks of glycolated samples were measured. Chlorite was discriminated by heating to 575°C. This method yields only semi-quantitative estimates of the abundances of the phases present.

The clay mineral phases identified in the overburden are smectite, illite, kaolinite, and chlorite (Figure 25). In all three coreholes, smectite is the most abundant phase present. The smectite content of bedrock overburden samples varies between 27 and 96 percent of the clay minerals (Figure 26). The average smectite content of the bedrock at HV17, HV19, and HV24 is 49, 72, and 70 percent, respectively. Illite comprises between 2 and 49 percent of the clays for all bedrock samples (Figure 26) and averages 27, 16, and 13 percent for coreholes HV17, HV19, and HV24, respectively. Chlorite occurs in small amounts of 0 to 12 percent of the clay mineral suite and averages between 2 and 4 percent for the three coreholes. The clays within the bedrock overburden occur as both grain coatings and fillings extending into the pore space.

The clay mineralogy of the glacial drift is similar to that of the bedrock in coreholes HV17 and HV19, but differs from the bedrock clay mineralogy in corehole HV24. At HV24, smectite and illite occur in the drift in similar amounts, comprising 39 and 37 percent, respectively, of the clay mineral suite. The relative abundance of chlorite within drift at HV24 averages 10.1 percent, which is notably higher than within the underlying bedrock at this site and also notably higher than the drift and bedrock at HV17 and HV19.

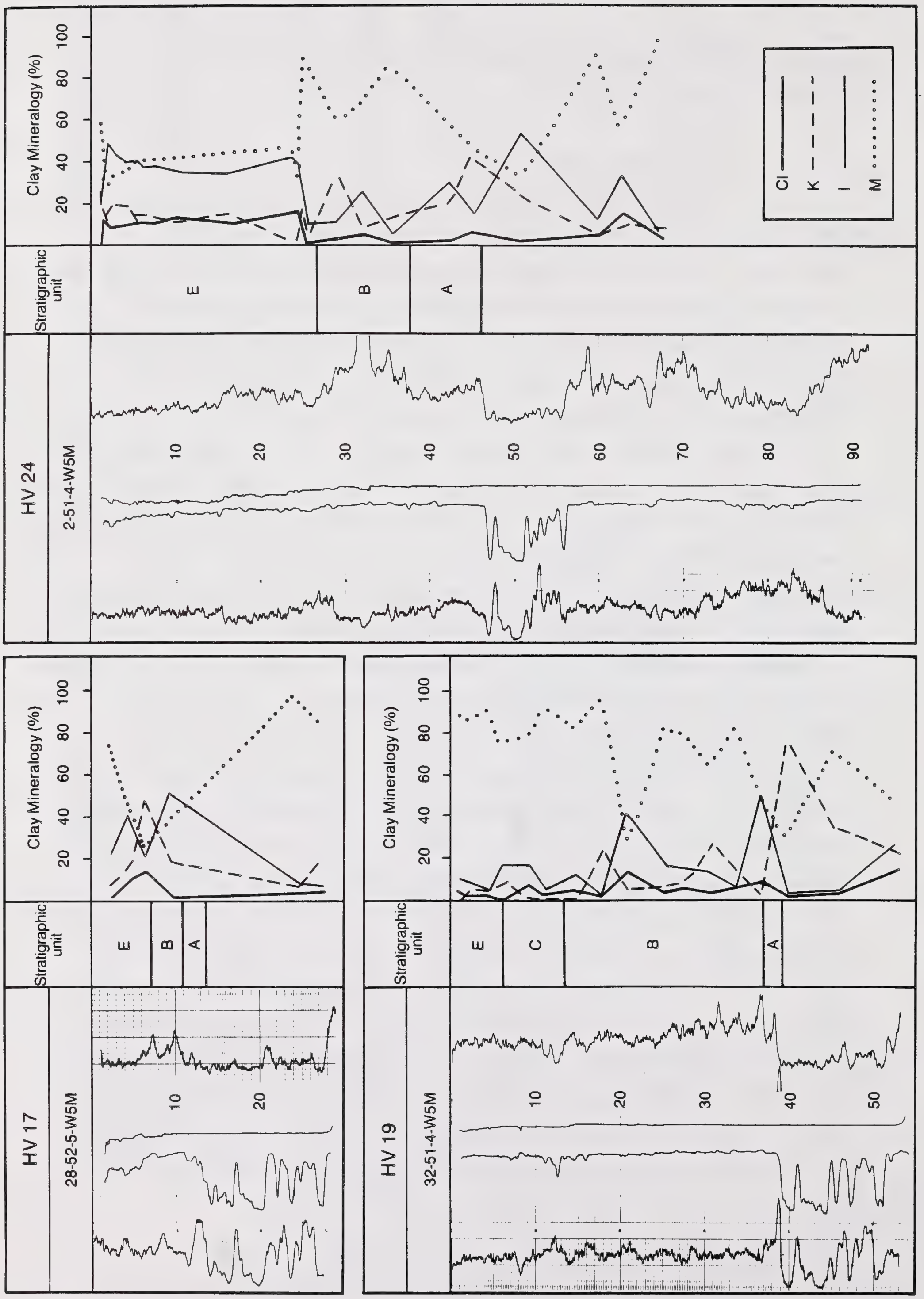

Figure 25. Distribution of clay minerals in coreholes HV-17, HV-19, and HV-24, Highvale study area.

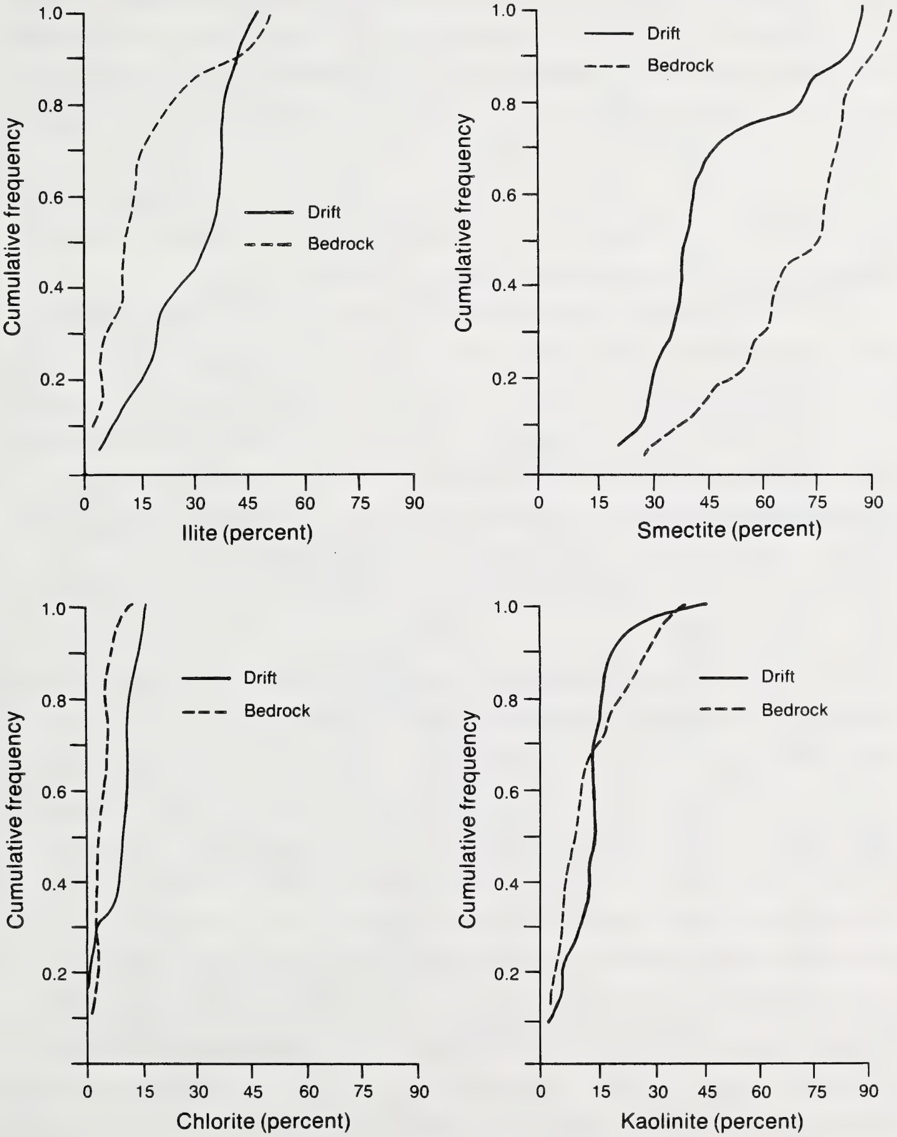

Figure 26. Cumulative frequency distribution of clay mineral species in 19 samples of drift and 22 samples of bedrock, Highvale study area.

8.3 CARBONATE ANALYSES

The total carbonate equivalent as determined by the gravimetric method within the bedrock overburden varies between 1.2 and 40.3 percent (Figure 27), but averages 1.8, 5.7, and 10.2 percent for HV17, HV19, and HV24, respectively. In general, the sandstone beds within the overburden are only slightly to moderately calcareous when tested with 10 percent HCl, however, along certain horizons such as at 31.4 m depth in corehole HV24, the sandstone is extremely well cemented and indurated. The carbonate minerals occur as secondary cement within the overburden bedrock sediment.

In general, the carbonate content of the drift and bedrock are very similar (Figure 28). The carbonate content of the glacial drift averages 5.8, 4.3, and 5.5 percent, respectively, for samples from sites HV17, HV19, and HV24. The drift at HV19 and HV24 contains less carbonate than the underlying bedrock. At HV17 the reverse is observed and the drift averages 5.8 percent carbonate, whereas the bedrock contains only an average of 1.8 percent.

8.4 PYRITE

Fresh, unoxidized pyrite was not observed in core from the overburden. Numerous oxidation rings, however, were detected in the core after it had been in storage for one year. These rings were not detected during the initial examination of the core, which took place very shortly after it was extracted. The rings appear to be the same as those observed in core of the Horseshoe Canyon Formation from the Battle River Study site (Maslowski Schutze et al. in press). They consist of a very dark grey to black, carbonaceous fragment surrounded by a yellowish-brown halo of iron oxide that extends three-dimensionally into the sediment. The rings are observed in medium-grey, silty shale and siltstone. It is believed that they are the alteration product of pyrite (Maslowski Schutze et al. in press).

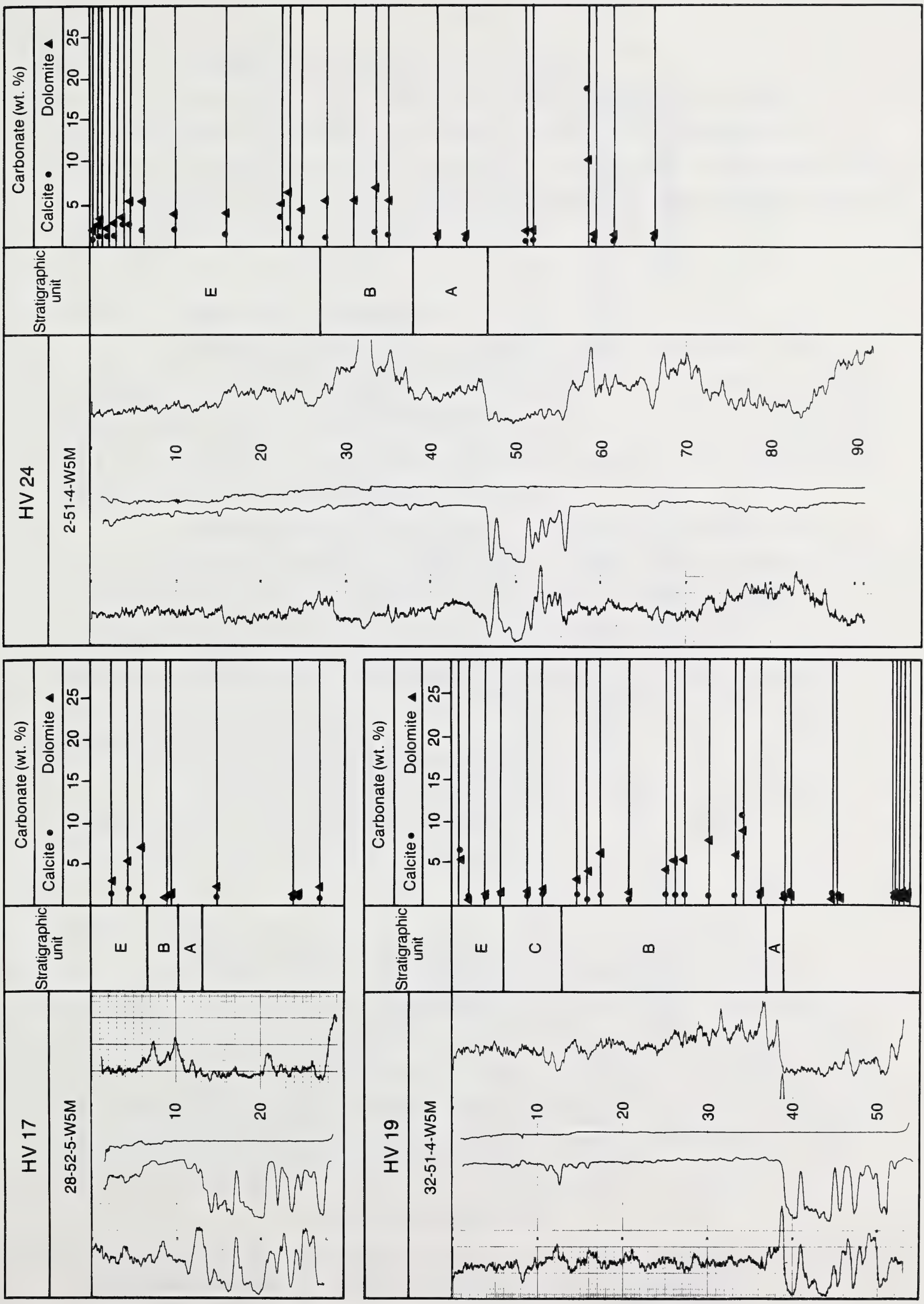

Figure 27. Distribution of carbonate minerals in coreholes HV-17, HV-19, and HV-24, Highvale study area.

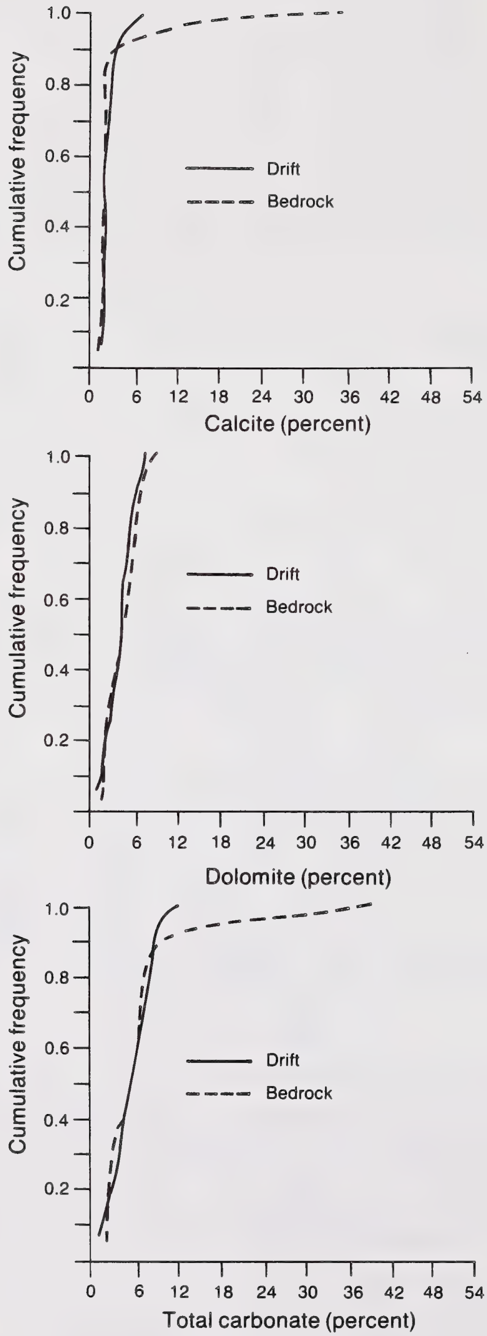

Figure 28. Cumulative frequency distributions of carbonate minerals in 19 samples of drift and 22 samples of bedrock, Highvale study area.

8.5 SATURATION-PASTE EXTRACTS

Saturation-paste extracts from the samples of the core collected during the PHRP study were prepared and analyzed by a commercial laboratory using the standard technique. Additional data were obtained from five previously completed reports. These data are discussed in the following section.

8.5.1 Saturation Percentage

The mean saturation percentage of the 19 glacial drift samples collected by PHRP is 84 percent (S.D. = 47 percent) and the median value is 67 percent (Figure 29). As can be seen in Figure 29, the distribution of saturation percentage values in the PHRP samples is typical of values throughout the site.

The saturation percentage of 22 bedrock samples from units A through C, that were collected by PHRP, varies between 28 and 176 percent. The mean saturation percentage of these samples is 76 percent and the median value is 73 percent (Figure 29). As can be seen in Figure 29, the PHRP samples give slightly lower values for saturation percentage than is typical of values reported from the bedrock in earlier studies.

For all the samples, saturation percentages are only slightly higher for bedrock samples than for drift samples (Figures 29, 30, 31, and 32; Table 1).

8.5.2 pH

Of 732 total pH determinations from the drift, 105, or 14.2 percent, have values less than 7.0 (Figure 33). The bedrock is much less acidic with only 4 of 176 values, or 2.3 percent, having values of 7.0 or less (Figures 30, 31, 32 and 33). This difference is reflected in the mean values from the various studies, which have mean values about half a pH unit lower for the drift than for the bedrock (Table 1).

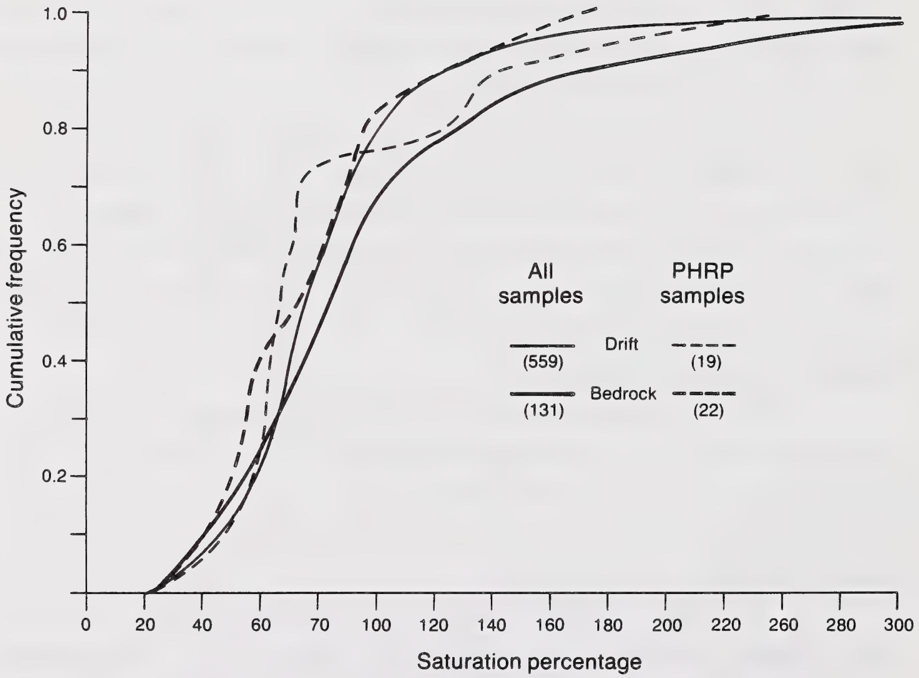

Figure 29. Cumulative frequency distributions of saturation percentage data from saturation-paste extracts of drift and bedrock samples showing comparison of PHRP data with all overburden data, Highvale study area.

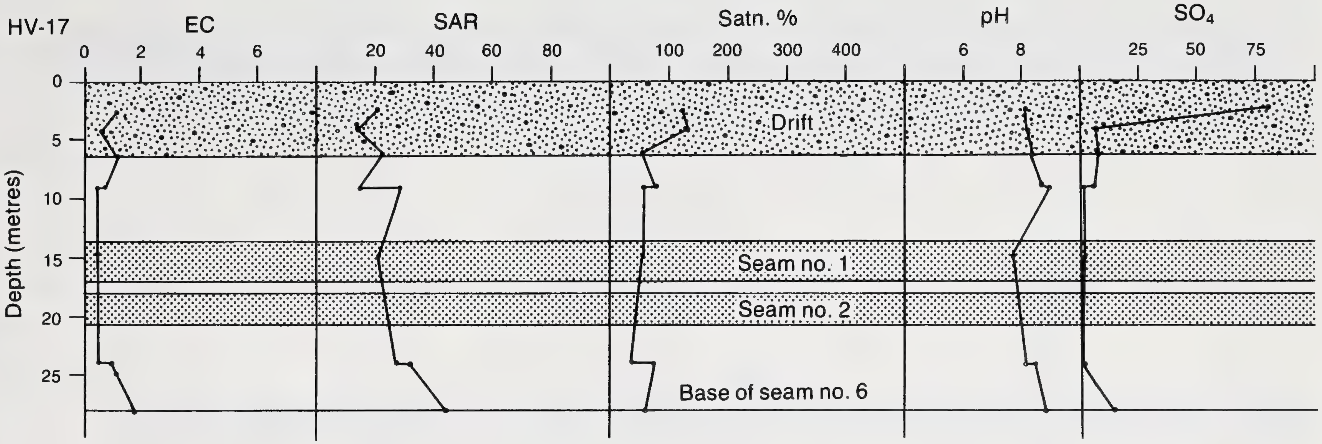

Figure 30. Plots by depth of electrical conductivity (EC), sodium adsorption ratio (SAR), saturation percentage (Satn %), pH, and sulfate concentration from saturation-paste extracts from corehole HV-17, Highvale study area.

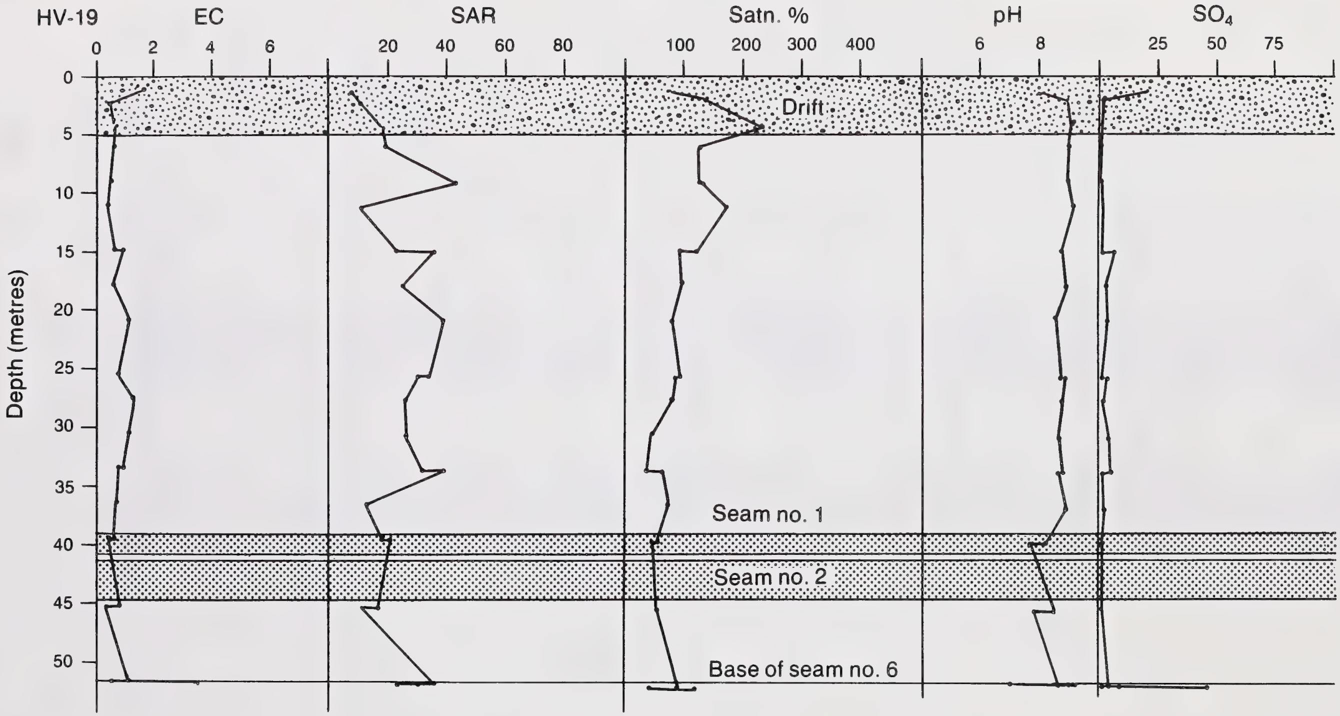

Figure 31. Plots by depth of electrical conductivity (EC), sodium adsorption ratio (SAR), saturation percentage (Satn %), pH, and sulfate concentration from saturation-paste extracts from corehole HV-19, Highvale study area.

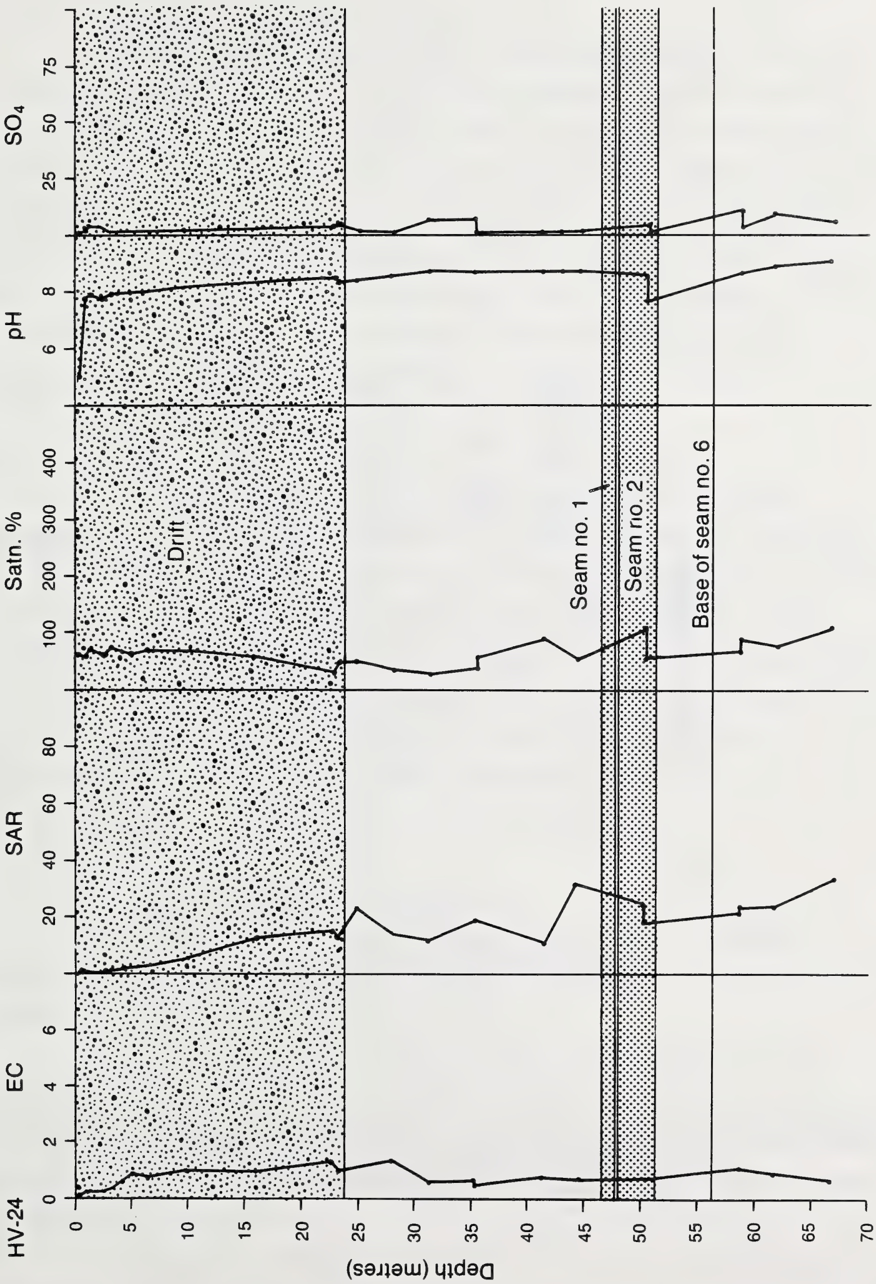

Figure 32. Plots by depth of electrical conductivity (EC), sodium adsorption ratio (SAR), saturation percentage (Satn %), pH, and sulfate concentration from saturation-paste extracts from corehole HV-24, Highvale study area.

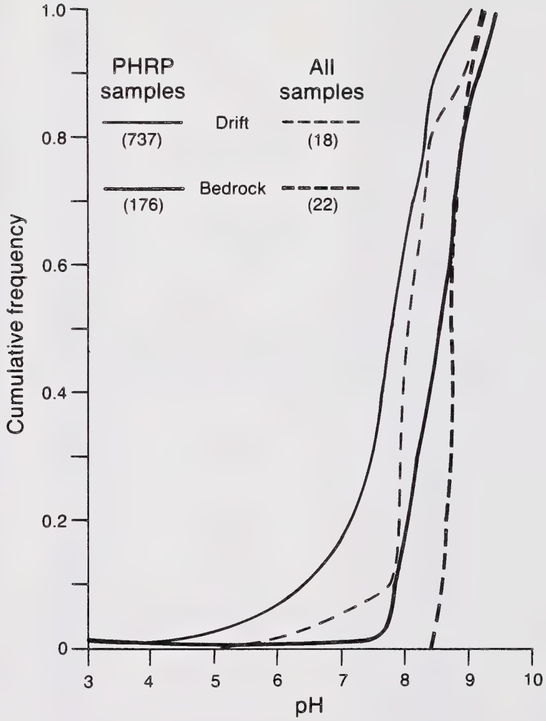

Figure 33. Cumulative frequency distributions of pH data for drift and bedrock samples showing comparison of PHRP data with all overburden data, Highvale study area.

8.5.3 Electrical Conductivity

Mean values of electrical conductivity (EC) of drift samples ranged from 0.75 to 1.57 dS/cm with an overall mean of 1.03 dS/cm (Table 1). Only 20 of 646 (3.1 percent) drift samples had conductivity values in excess of 4.0 dS/cm (Figure 34). Bedrock at Highvale is slightly more saline with mean conductivity values of individual studies ranging from 0.84 to 1.51 dS/cm (Table 1) and the overall mean of 1.21 dS/cm (Figure 34; Table 1). Maximum salinity values were lower for bedrock than drift with only 2 of 176 (1.1 percent) samples being greater than 4.0 dS/cm (Figure 34).

8.5.4 SAR

Sodium absorption ratio (SAR) values for drift are generally low (Figures 30, 31 and 32). Mean values for individual studies ranged from 2.8 to 8.9 with an overall mean of 4.6 (Table 1). About 8.25 percent of drift samples (54 of 654) had SAR values greater than 12 (Figure 35). The bedrock is more sodic with mean SAR values of individual studies ranging from 11.6 to 25.0 (Table 1). The overall mean was 15.7 (Table 1). More than two thirds (67.6 percent) of the samples had SAR values in excess of 12 with 117 of 176 samples having such high values (Figure 35).

8.5.5 Patterns in Extract Chemistry

On the basis of data from the PHRP samples, patterns can be seen in variation in overburden characteristics at Highvale Mine, especially in the drift.

The glacial drift at HV19, in the central part of the area, yields the highest mean pH, saturation percentage, smectite content, and cation exchange capacity. In contrast, the drift at HV24, the southernmost site studied, yields the lowest mean values for these variables.

The general trend in soluble sodium in the stratigraphic sequence at Highvale is toward an increase with depth, acquiring its highest values in the sediment beneath the coal zone. In addition,

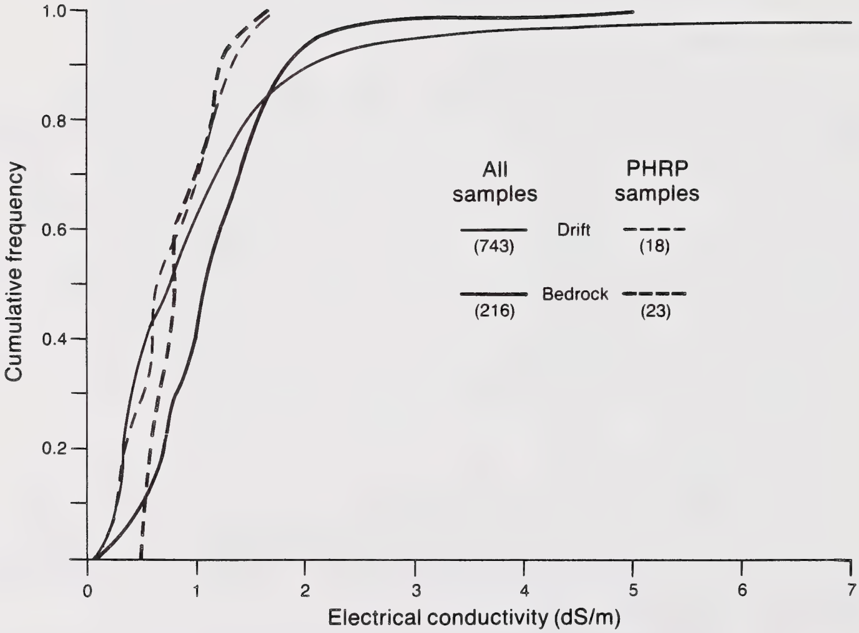

Figure 34. Cumulative frequency distributions of electrical conductivity data from saturation-paste extracts of drift and bedrock samples showing comparison of PHRP data with all overburden data, Highvale study area.

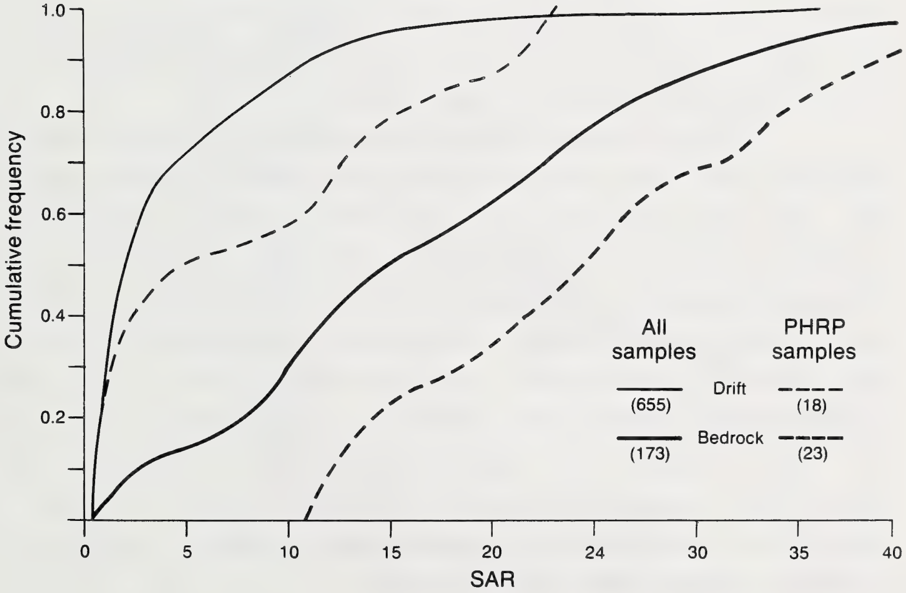

Figure 35. Cumulative frequency distributions of SAR data from saturation-paste extracts of drift and bedrock samples showing comparison of PHRP data with all overburden data, Highvale study area.

sodium content decreases to the south with concentrations at HV17, HV19, and HV24 being 12.10, 9.70 and 4.95, respectively.

Mean SAR in the drift decreases significantly toward the south from 19.4 at HV17, through 14.3 at HV19, to 4.6 at HV24. Presumably, this reflects a decrease in abundance of locally derived bedrock material in the drift.

In general, SAR increases with depth in the sediment at Highvale (Figures 30, 31 and 32).

The concentration of soluble sulfate within drift samples ranges from 0.5 to 80.5 meq/L. Eighty percent of the samples contain less than 6.9 meq/L soluble sulfate. The median concentration with drift samples is 2.0 meq/L (Figure 36).

The mean concentration of soluble sulfate in the drift samples follows a north-south trend in the Highvale study area. The mean concentrations of soluble sulfate at HV17, HV19, and HV24 are 31.8, 5.75, and 2.04 meq/L, respectively.

The mean concentration of soluble calcium within the drift increases from north to south in the study area; the mean values for HV17, HV19, and HV24 are 0.53, 1.37, and 2.52 meq/L, respectively. In general, soluble calcium decreases with depth. The concentration of soluble magnesium within the drift increases markedly toward the south. Mean concentrations at HV17, HV19, and HV24 are 0.2, 0.72, and 1.02 meq/L, respectively. This parallel increase in both calcium and magnesium in drift likely reflects a compositional shift in the till from a largely local bedrock-derived source in the north to a more distant source to the south. It likely reflects a greater abundance of lower Paleozoic carbonate rock material, particularly dolomite, in the south.

8.6 CATION EXCHANGE CHARACTERISTICS

The cation exchange capacity of overburden samples collected as part of the PHRP study was determined at Norwest Laboratories Ltd. The extract was buffered to pH7 and ammonium

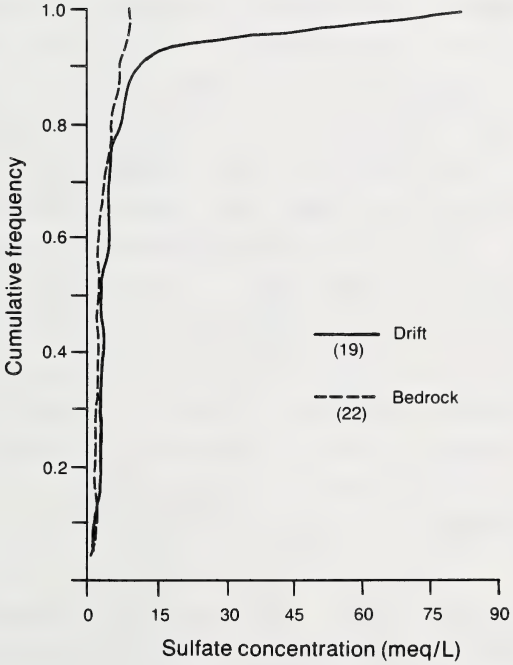

Figure 36. Cumulative frequency distributions of sulfate concentration data from saturation-paste extracts of 19 drift samples and 22 bedrock samples, Highvale study area.

acetate was used as the extractant. The exchangeable cations were analyzed using Atomic Adsorption Spectroscopy.

The mean cation exchange capacity of drift samples is 20.5 meq/100 g (S.D. = 6.64) with a median value of 20.0 meq/100 g (Figure 37).

The mean CEC of 22 samples from units A, B and C of the bedrock is 20.31 meq/100 g (S.D. = 5.31) and the median value is 19.8 meq/100 g (Figure 37). Individual bedrock samples had values ranging between 8.2 and 28.8 meq/100 g. The mean value for exchangeable calcium within the drift is 19.73 meq/100 g (S.D. = 4.33) and the median value is 20.6 meq/100 g.

The range of values for exchangeable calcium in 22 samples from units A, B and C is between 9.2 and 23.4 meq/100 g. The mean value for exchangeable calcium in these samples is 15.67 meq/100 g (S.D. = 3.41) and the median value is 15.6 meq/100 g. The highest mean value for exchangeable calcium is noted within the carbonaceous shale associated with the coal zone. The mean for these samples is 22.38 meq/100 g (S.D. = 6.09) and the median is 23.8 meq/100 g.

Exchangeable magnesium is significantly less than calcium. The mean value for exchangeable magnesium within the drift is 4.5 meq/100 g (S.D. = 1.93) and the median value is 4.8 meq/100 g. Exchangeable magnesium within 22 samples from bedrock units A, B and C varies between 1.3 and 5.1 meq/100 g. The mean is 2.29 meq/100 g and the median is 2.2 meq/100 g.

Exchangeable sodium within the drift varies from 0.9 to 21.8 meq/100 g. The mean and median values are 7.29 and 7.1 meq/100 g, respectively. Exchangeable sodium within the bedrock overburden varies from 1.3 to 16.4 meq/100 g. The mean and median values for exchangeable sodium within the bedrock overburden, units A, B and C inclusive, are 9.73 and 10.6 meq/100 g. Exchangeable sodium within carbonaceous shale associated with the coal zone varies between 9.6 and 24.8 meq/100 g. The mean and median values are 15.06 meq/100 g (S.D. = 6.21) and 12.8 meq/100 g. Exchangeable sodium in clay partings in the coal zone varies between 9.0 and 12.1 meq/100 g. The mean value is 10.67 meq/100 g.

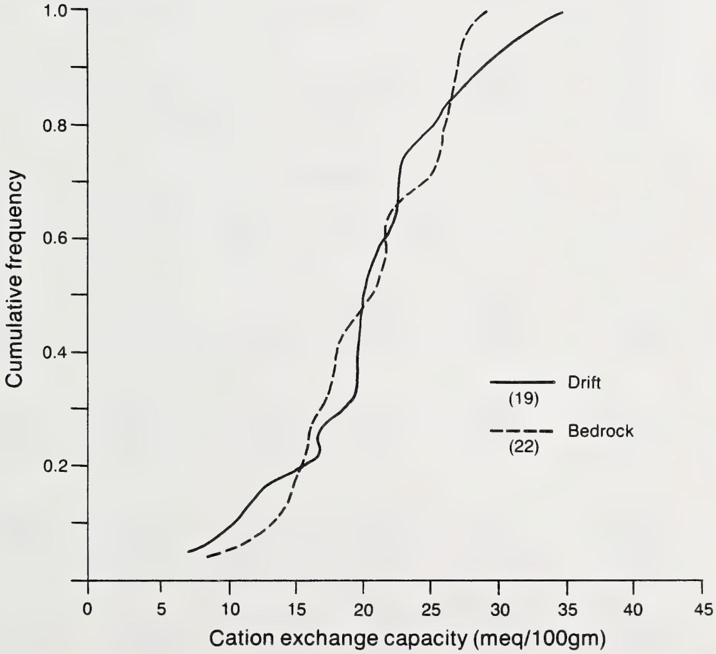

Figure 37. Cumulative frequency distributions of cation exchange capacity data from 19 drift and 22 bedrock samples, Highvale study area.

Table 1. Mean and median values of pH, EC, Sat % and SAR calculated for drift and bedrock samples from the six studies

	Glacial Drift						
	PHRP[a]	X1[b]	X2[c]	X3[d]	X4[e]	X5[f]	Overall Means
Samples	19	144	15	99	96	334	746
pH							
mean	8.1	8.1	7.5	8.1	8.1	7.2	7.6
median	8.1	8.2	7.8	8.2	8.2	7.5	
EC							
mean	0.75	1.57	0.93	0.84	0.84	0.93	1.03
median	0.63	0.86	0.90	0.84	0.81	0.60	
Sat %							
mean	84.0	67.0				86.0	81.0
median	67.0	64.0	62.0			81.0	
SAR							
mean	8.9	7.9	2.8	4.4	4.4	3.3	4.6
median	8.1	4.8	1.8	1.9	2.2	1.5	
				Bedrock			
Samples	22		76	45	55	34	232
pH							
mean	8.7	N/A	7.6	8.6	8.6	8.1	8.2
median	8.7	N/A	7.9	8.7	8.7	8.1	
EC							
mean	0.84	N/A	1.51	1.02	1.0	1.40	1.21
median	0.79	N/A	1.50	0.90	0.90	1.10	
Sat %							
mean	76.0	N/A	82.0	N/A	N/A	106.0	87.0
median	73.0	N/A	83.0	N/A	N/A	87.0	
SAR							
mean	25.0	N/A	11.6	17.9	17.9	12.3	15.7
median	24.5	N/A	10.0	16.6	16.6	12.0	

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[a] PHRP Plains Hydrology Reclamation Project, 1982
[b] X1 Montreal Engineering, 1982
[c] X2 Montreal Engineering, 1980
[d] X3 Montreal Engineering, 1977a
[e] X4 Montreal Engineering, 1977b
[f] X5 Alberta Environment, 1977

8.7 SUMMARY

Analyses of nearly 1000 overburden samples from the Highvale study area have been reviewed. The majority of the analyzed samples (746) were from the drift, the remaining 232 were from bedrock. Nearly all of the drift samples were low salinity, low sodicity, and were suitable as sub-soil material for reclamation. Only about 20 of the 746 drift samples (2.5 percent) have EC values greater than 4.0; about 60 of the 634 samples (9.6 percent) have SAR values greater than 10. By comparison, most of the bedrock samples are unsuitable as subsoil because of sodicity. Only 2 of 216 samples of bedrock have conductivity values greater than 4.0; 27 of 183 samples of bedrock (69.4 percent) have SAR values greater than 10.

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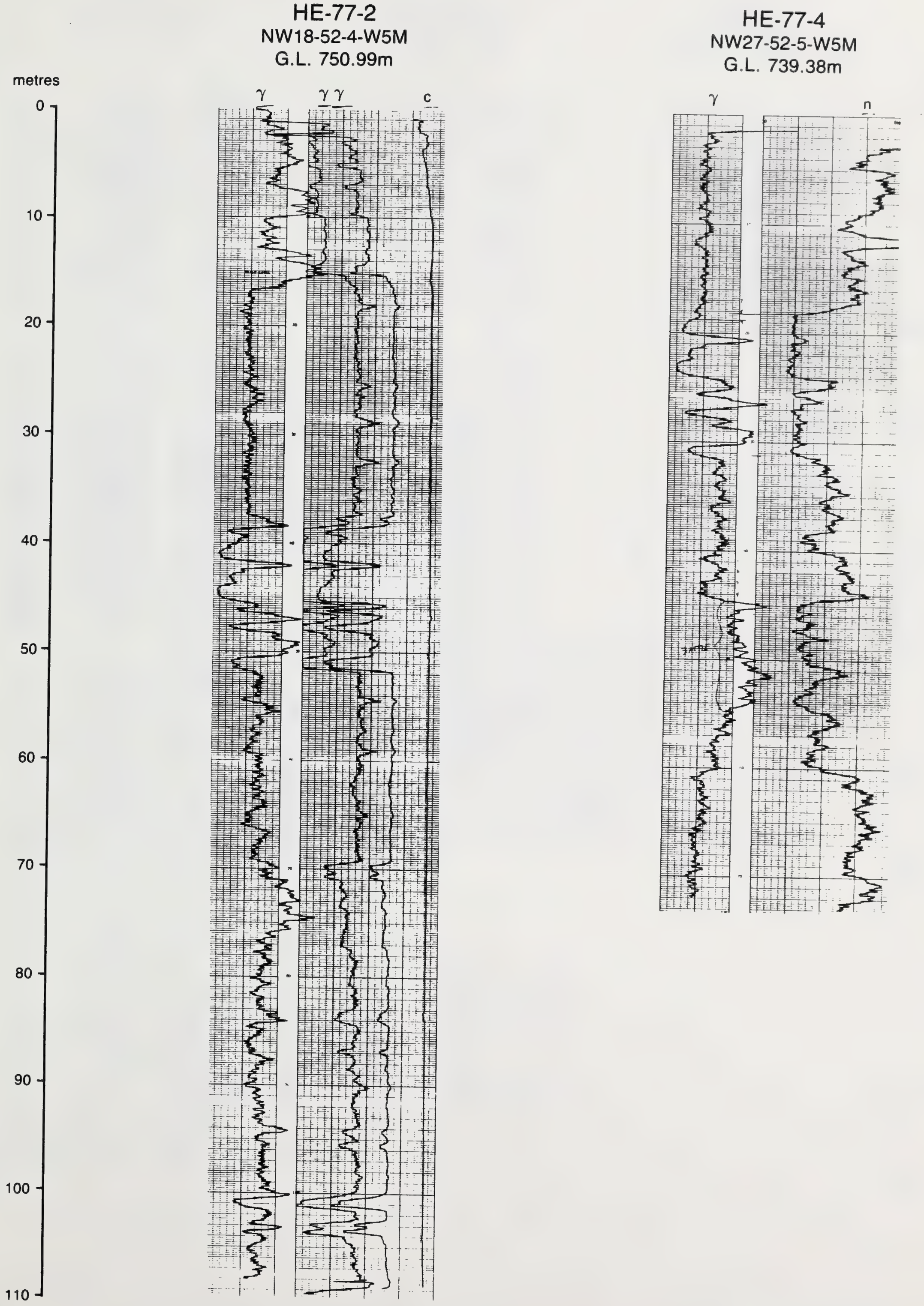
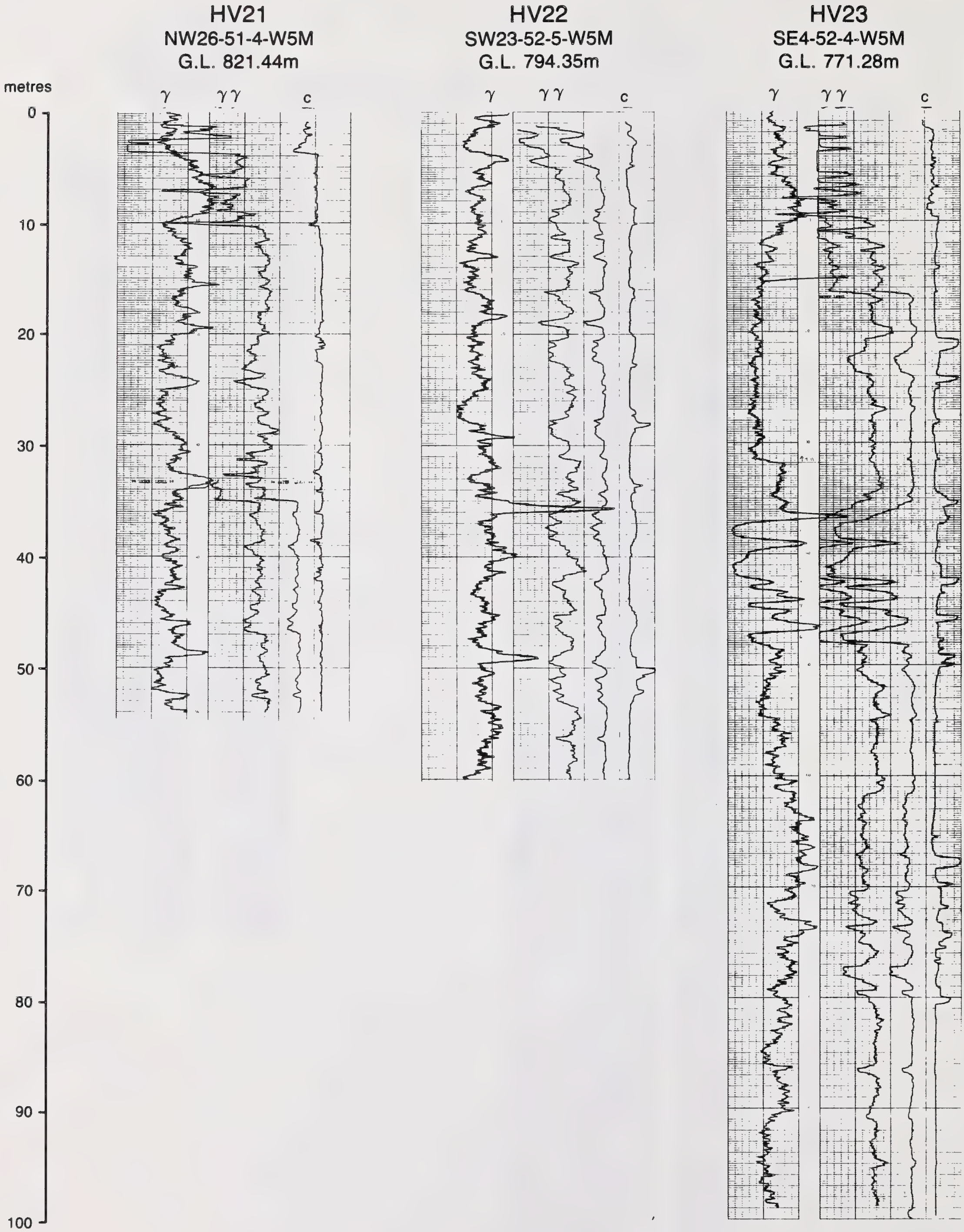
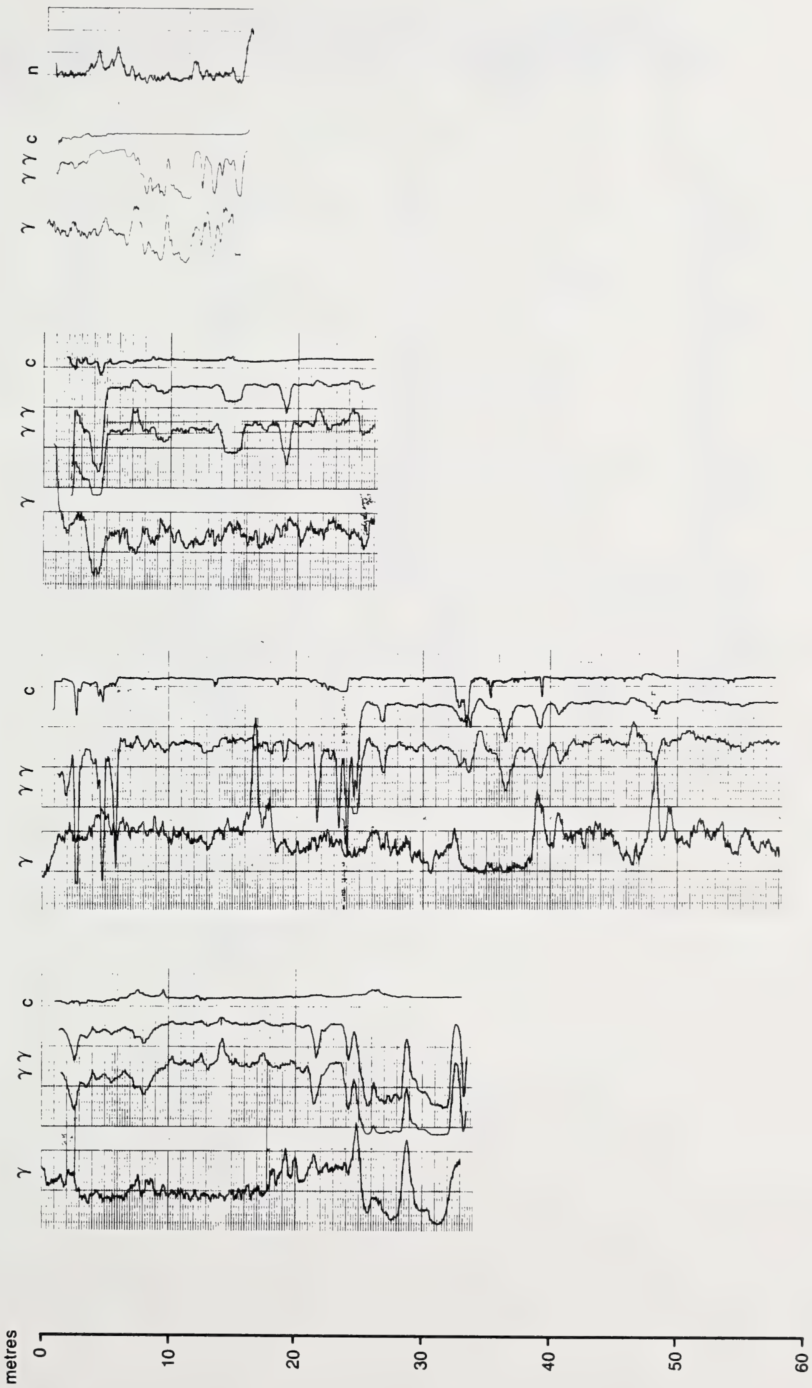
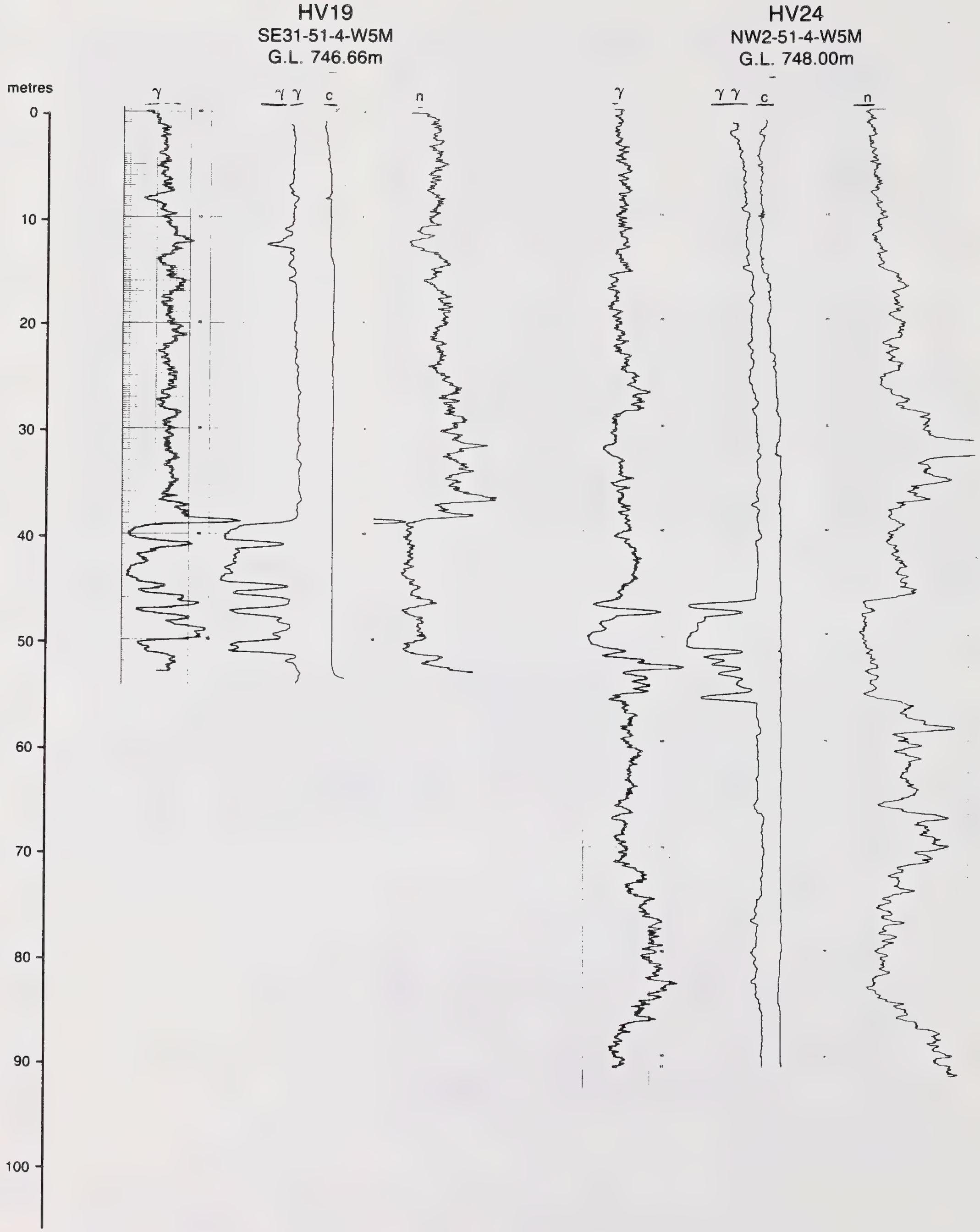
10. APPENDIX A - GEOGRAPHICAL LOGS OF BOREHOLES IN THE HIGHVALE STUDY AREA

	Page
HE-77-22	67
HE-77-4	67
HV21	68
HV22	68
HV23	68
HV13	69
HV15	69
HV16	69
HV17	69
HV19	70
HV24	70


HE-77-2
NW18-52-4-W5M
G.L. 750.99m
HE-77-4
NW27-52-5-W5M
G.L. 739.38m
metres
0
10
20
30
40
50
60
70
80
90
100
110
γ
γ γ
c
γ
n


HV21
NW26-51-4-W5M
G.L. 821.44m
HV22
SW23-52-5-W5M
G.L. 794.35m
HV23
SE4-52-4-W5M
G.L. 771.28m
metres
γ
γγ
c
0
10
20
30
40
50
60
70
80
90
100


HV17
NW28-52-5-W5M
G.L. 736.28m
γ
γγ
c
n
HV16
SE29-52-5-W5M
G.L. 749.49m
γ
γγ
c
HV15
NE22-52-5-W5M
G.L. 800.31m
γ
γγ
c
HV13
SE25-52-5-W5M
G.L. 751.46m
γ
γγ
c
metres
0
10
20
30
40
50
60


HV19
SE31-51-4-W5M
G.L. 746.66m
HV24
NW2-51-4-W5M
G.L. 748.00m
metres
0
10
20
30
40
50
60
70
80
90
100
γ
γ γ
c
n
γ
γ γ
c
n

11. APPENDIX B CHEMICAL AND PHYSICAL ANALYSIS OF OVERBURDEN SAMPLES FROM THE HIGHVALE STUDY AREA

SITE	DEPTH (m)	STRAT.	LITHOLOGY	pH	EC (dS/m)	SAT%	SATURATION EXTRACT Ca	Mg	Na	SO4	HCO3	Cl	K	SAR
							<—			mg/L			—>	
17	2.44	1	TILL	8.1	1.15	120.0	.60	.20	13.90	80.50	39.10	.20	.28	21.10
	4.27	1	TILL	8.2	.63	131.0	.40	.20	7.60	6.90	49.30	.20	.23	14.10
	6.10	1	TILL	8.3	1.20	55.0	.60	.20	14.80	8.00	10.90	1.40	.38	22.90
	9.00	4	SHALE	8.7	.79	79.0	.60	.30	10.40	6.50	32.80	.50	.56	15.40
	9.00	4	SANDSTONE	8.9	.56	59.0	.10	0.0	7.10	.60	20.30	.30	.18	24.50
	15.00	6	PARTING	7.7	.51	52.0	.10	.10	6.50	.50	30.50	.10	.13	21.30
	24.00	6	PARTING	8.1	.53	37.0	.10	.10	8.30	.30	42.80	.30	.13	27.00
	24.00	6	PARTING	8.4	.94	76.0	.10	.20	13.00	.60	50.90	.50	.18	32.00
	27.00	6	SANDSTONE	8.8	1.70	61.0	.40	.10	20.40	13.70	2.80	5.60	.26	43.70
19	1.22	1	SILT	8.0	1.65	71.0	4.30	2.50	14.80	18.70	12.60	.10	.69	8.10
	2.44	1	CLAY	9.0	.52	139.0	.70	.20	7.70	2.00	30.00	.20	.33	11.20
	4.27	1	TILL	9.1	.63	236.0	.20	.20	8.70	1.10	32.60	.10	.32	18.20
	6.10	1	MUDSTONE	9.0	.62	125.0	.30	0.0	7.60	1.20	45.10	.10	.15	19.60
	9.14	3	MUDSTONE	9.0	.59	125.0	0.0	0.0	7.90	.90	35.10	.10	.15	43.60
	11.00	3	SILTSTONE	9.2	.49	176.0	.40	.20	6.20	2.10	21.50	.30	.13	11.50
	14.80	4	SILTSTONE	8.8	.65	121.0	.10	.10	7.60	1.50	34.80	.20	.18	22.80
	14.80	4	SILTSTONE	8.8	1.00	95.0	.10	.10	11.70	5.70	22.90	2.50	.31	36.40
	17.80	4	SANDSTONE	8.9	.65	97.0	.10	.10	7.70	2.70	31.00	.50	.18	24.90
	20.80	4	SHALE	8.5	1.20	81.0	.20	.10	16.10	3.20	21.40	.40	.36	39.40
	25.50	4	SHALE	8.7	.79	92.0	.10	.10	10.40	1.90	27.70	.70	.21	34.10
	25.50	4	SHALE	8.8	.80	89.0	.10	.10	10.40	2.70	29.50	1.10	.21	30.90
	27.50	4	SILTSTONE	8.7	1.30	80.0	.60	.40	19.10	1.30	29.40	1.00	.51	26.30
	30.50	4	SANDSTONE	8.6	1.15	50.0	.40	.20	13.90	4.40	15.60	2.10	.28	26.80
	33.50	4	SILTSTONE	8.7	.98	64.0	.20	.10	12.60	5.10	22.10	2.10	.23	31.90
	33.50	4	SANDSTONE	8.6	.84	39.0	.10	.10	12.60	1.60	26.30	.40	.21	39.10
	36.50	5	SILTSTONE	8.9	.76	73.0	.70	.50	10.00	.80	18.90	1.00	.64	12.50
	39.50	7	PARTING	8.2	.63	54.0	.50	.50	13.00	.40	4.00	1.40	.24	18.90
	39.50	6	PARTING	7.7	.54	49.0	.10	.10	6.40	.90	40.40	.70	.15	21.00
	45.25	7	PARTING	8.5	.89	55.0	.70	.50	13.00	.20	34.40	1.40	.51	16.70
	45.25	6	PARTING	7.8	.42	57.0	.20	.10	5.00	.30	54.60	.60	.13	11.60
	52.00	8	SHALE	8.7	1.15	91.0	.20	.10	15.20	4.90	23.60	1.30	.31	36.20
	52.00	8	SHALE	6.9	3.40	40.0	3.50	.50	43.50	46.20	0.0	.90	.49	30.80
	52.00	8	SHALE	9.0	1.10	88.0	.20	.10	13.50	8.00	27.90	.20	.51	34.10
	52.00	8	SANDSTONE	9.1	.59	119.0	.10	0.0	6.80	1.90	38.30	.60	.15	23.70

SITE	DEPTH (m)	STRAT.	LITHOLOGY	pH	EC (dS/m)	SAT%	SATURATION EXTRACT							SAR
							Ca	Mg	Na	SO4	HCO3	Cl	K	
							<——			mg/L			——>	
24	.45	1	CLAY	5.1	.12	62.0	.70	.30	.40	.50	37.50	.20	.08	.60
	.91	1	CLAY	7.8	.28	59.0	2.30	1.00	.80	1.80	38.00	.20	.13	.60
	1.37	1	CLAY	7.9	.31	71.0	2.40	1.10	.80	3.20	33.70	.10	.13	.60
	2.29	1	CLAY	7.8	.30	62.0	2.10	1.00	1.00	3.60	28.00	.10	.15	.80
	3.20	1	CLAY	8.0	.34	72.0	2.40	1.20	1.20	1.00	35.40	.20	.18	.90
	4.10	1	TILL	8.0	.62	69.0	4.00	1.70	2.40	1.70	28.00	.20	.33	1.40
	5.03	1	TILL	8.0	.86	62.0	5.40	2.10	3.60	.80	30.80	1.00	.38	1.90
	6.40	1	TILL	8.1	.77	67.0	4.00	1.40	4.30	.70	31.40	1.00	.38	2.60
	9.91	1	TILL	8.2	1.05	66.0	3.40	1.00	7.50	1.00	29.90	1.60	.41	5.10
	16.00	1	SAND	8.3	.99	53.0	1.10	.40	10.90	2.70	18.00	.20	.33	12.40
	22.86	1	SAND	8.4	1.30	28.0	1.40	.40	14.80	2.80	11.70	.20	.31	15.60
	23.50	1	SAND	8.3	.97	49.0	1.10	.60	11.70	4.70	21.60	.30	.51	12.60
	25.00	4	SILTSTONE	8.4	1.15	51.0	.40	.20	12.60	2.10	3.00	3.00	.23	23.40
	28.00	4	SANDSTONE	8.6	1.35	35.0	1.60	.60	14.80	.90	12.20	.80	.28	14.00
	31.40	4	SANDSTONE	8.8	.61	28.0	.40	.20	6.50	7.50	15.40	.60	.21	12.10
	35.40	4	SANDSTONE	8.7	.71	38.0	.20	.10	7.80	7.10	17.90	.60	.18	19.20
	35.40	4	SHALE	8.7	.54	55.0	.10	.10	6.30	1.10	31.50	.10	.15	18.70
	41.40	5	SHALE	8.8	.79	88.0	2.50	.60	13.50	1.20	28.50	.80	1.54	10.80
	44.40	5	SILTSTONE	8.7	.75	54.0	.10	.10	9.60	1.80	25.90	.10	.21	31.30
	50.40	7	PARTING	8.6	.77	104.0	.10	.20	10.00	3.40	30.00	.20	.28	24.60
	50.40	6	PARTING	7.7	.73	52.0	.40	0.0	8.30	1.70	32.20	.10	.13	18.10
	58.90	8	SANDSTONE	8.7	1.05	65.0	1.10	.20	17.00	10.50	21.60	1.00	.46	20.80
	58.90	8	SILTSTONE	8.7	1.10	83.0	.50	.20	13.50	3.80	24.70	1.40	.69	22.70
	61.90	8	SILTSTONE	8.9	.90	73.0	.50	.20	14.30	9.50	18.30	.90	.74	24.10
	66.80	8	SANDSTONE	9.1	.75	106.0	.10	.10	10.00	5.30	10.90	.20	.15	32.70

		EXCHANGEABLE CATIONS					CARBONATE			CLAY MINERALOGY			
SITE	DEPTH	Ca	Mg	Na	K	CEC	Cal	Dol	Total	Sm	Ill	Kaol	Chl
17	2.44	25.70	4.70	10.30	.90	30.2	1.1	2.6	3.6	71	21	7	0
	4.27	21.40	2.90	7.10	.72	23.8	1.7	4.8	6.5	41	38	14	8
	6.10	12.40	2.10	5.20	.64	16.5	.7	6.6	7.3	23	20	45	12
	9.00	23.30	2.60	12.70	1.18	26.0	.7	.7	1.5	36	48	16	0
	9.00	12.60	1.60	6.50	.49	17.7	.9	1.3	2.3	61	6	29	5
	15.00	19.20	1.90	9.60	.38	18.2	.6	1.7	2.3				
	24.00	27.90	2.10	12.80	.64	32.6	.6	.9	1.5				
	24.00	25.70	2.70	22.60	1.03	33.1	.9	1.1	1.9	92	5	3	0
	27.00	10.80	1.20	9.60	.51	20.0	.6	1.9	2.6	80	3	15	2
19	1.22	20.60	7.20	2.90	.74	18.9	6.4	5.1	11.5	87	10	0	3
	2.44	18.40	3.10	9.80	.87	21.9	.9	.5	1.4	85	8	5	2
	4.27	17.70	2.00	13.20	.88	28.0	.9	1.0	1.9	89	5	4	2
	6.10	21.00	2.40	21.80	1.21	34.6	1.2	1.2	2.4	74	17	9	0
	9.14	17.00	1.80	16.40	.94	25.6	1.0	1.5	2.5	77	16	0	7
	11.00	11.30	1.30	10.70	.58	21.1	1.2	1.5	2.7	91	5	1	2
	14.80	18.90	2.60	14.10	.88	26.7	1.1	2.8	4.0	81	11	4	4
	14.80	16.00	2.30	12.00	.77	26.0	.4	3.7	4.1	66	21	10	4
	17.80	17.60	2.50	13.30	.79	28.8	1.0	5.9	6.9	95	2	1	2
	20.80	13.10	1.90	9.20	.84	17.3	.3	.9	1.2	27	40	22	12
	25.50	15.30	2.20	12.00	.76	20.9	1.0	4.1	5.2	79	14	5	2
	25.50	16.90	2.40	13.20	.82	19.8	.9	5.4	6.4	82	12	3	3
	27.50	16.40	2.60	11.90	.77	22.9	1.0	5.1	6.1	76	13	8	4
	30.50	11.80	1.80	8.00	.54	17.3	.9	7.4	8.3	62	11	24	2
	33.50	15.20	2.70	10.60	.81	21.5	1.1	5.4	6.5	79	5	12	4
	33.50	19.00	1.30	6.90	1.05	13.1	10.5	8.4	18.9	82	5	10	3
	36.50	11.70	1.60	6.90	.50	15.6	.8	.4	1.3	45	49	0	6
	39.50	19.10	2.90	9.00	1.36	26.2	.8	1.3	2.2	27	0	73	0
	39.50	23.80	2.60	14.80	.76	20.8	1.3	.3	1.7				
	45.25	21.90	2.30	10.90	.93	33.7	1.3	.8	2.1	68	0	32	0
	45.25	28.20	2.10	24.80	.43	29.5	1.0	.4	1.4				
	52.00	12.70	1.50	14.10	1.39	19.1	.3	1.2	1.6	44	23	21	12
	52.00	13.30	1.20	13.50	.64	15.2	1.0	.4	1.4	83	9	9	0
	52.00	23.60	2.10	10.00	.37	25.1	.2	1.6	1.8	80	8	12	0
	52.00	12.40	1.40	26.60	.43	24.8	.8	1.1	1.8	88	2	9	1

SITE	DEPTH	Ca	EXCHANGEABLE CATIONS Mg	Na	K	CEC	Cal	CARBONATE Dol	Total	Sm	CLAY MINERALOGY Ill	Kaol	Chl
24	.45	18.00	6.70	13.10	.38	22.0	.6	.2	.8	56	21	23	0
	.91	20.30	6.20	13.10	.44	21.0	1.0	2.6	3.7	43	33	15	9
	1.37	22.30	6.40	7.70	.59	19.3	1.1	3.4	4.5	28	47	14	11
	2.29	18.40	5.90	6.80	.66	22.3	1.2	2.3	3.5	32	42	18	9
	3.20	21.10	7.00	7.80	.73	19.2	1.3	2.8	4.0	34	38	18	10
	4.10	22.30	5.90	.90	.79	16.7	2.7	3.5	6.1	37	40	13	10
	5.03	24.90	5.60	1.30	.78	20.0	2.5	5.4	7.9	38	37	14	11
	6.40	24.80	5.50	2.20	.58	19.6	2.0	5.5	7.5	40	37	13	10
	9.91	24.80	4.80	2.50	.35	12.5	2.0	3.7	5.7	41	35	11	13
	16.00	15.40	3.00	1.93	.58	6.8	1.4	3.9	5.3	43	33	14	10
	22.86	9.50	1.30	3.30	.62	10.2	3.4	5.0	8.5	45	40	0	15
	23.50	15.80	2.80	7.70	.27	26.0	2.1	6.5	8.6	32	38	17	14
	25.00	20.20	5.10	2.50	.29	15.6	.9	4.4	5.2	87	9	3	1
	28.00	9.20	3.00	1.30	.39	8.2	.7	5.5	6.3	57	10	32	2
	31.40	17.10	2.00	3.90	.48	16.0	34.6	5.6	40.3	66	24	6	4
	35.40	14.80	3.00	6.60	1.17	15.6	1.6	7.3	8.9	83	4	12	1
	35.40	15.60	2.30	14.30	.48	27.1	1.2	5.5	6.7	96	2	0	2
	41.40	19.40	2.20	7.70	1.17	19.1	.9	1.2	2.0	55	27	18	0
	44.40	12.30	1.50	13.40	.62	24.9	.9	1.1	1.9	44	14	39	4
	50.40	19.00	1.60	12.10	.92	29.8	.4	1.9	2.3	30	50	20	0
	50.40	21.10	1.20	11.20	.54	15.6	.6	1.7	2.3				
	58.90	17.90	1.00	13.60	.62	19.5	18.8	9.5	28.3	86	10	2	2
	58.90	12.80	1.20	14.90	1.01	21.6	.8	1.3	2.1	28	35	11	26
	61.90	14.20	1.20	12.30	1.02	20.7	.7	1.3	2.0	51	30	7	12
	66.80	11.90	1.00	2.90	.55	12.3	.9	1.5	2.4	96	0	4	0

		GRAIN SIZE ANALYSES % FINER (units = micrometers)											SULFUR ISOTOPES		
SITE	DEPTH	2000	1000	500	250	100	63	50	20	10	4	2	Sol S	Insol S	Total S
17	2.44	100	99	Na	Na	Na	83	82	Na	Na	43	35			
	4.27	100	99	Na	Na	Na	69	67	Na	Na	38	32			
	6.10	100	100	Na	Na	Na	99	98	Na	Na	24	17			
	9.00	100	99	Na	Na	Na	95	94	Na	Na	11	6			
	9.00	100	100	Na	Na	Na	51	47	Na	Na	22	16			
	15.00														
	24.00														
	24.00	100	100	Na	Na	Na	86	84	Na	Na	55	42			
	27.00	100	100	Na	Na	Na	42	39	Na	Na	22	19			
19	1.22	100	100	Na	Na	Na	56	51	Na	Na	25	21			
	2.44	100	100	Na	Na	Na	69	64	Na	Na	35	29			
	4.27	100	100	Na	Na	Na	64	60	Na	Na	32	28			
	6.10	100	100	Na	Na	Na	97	94	Na	Na	50	36			
	9.14	100	100	Na	Na	Na	92	86	Na	Na	34	25			
	11.00	100	100	Na	Na	Na	45	42	Na	Na	21	20			
	14.80	100	100	Na	Na	Na	99	98	Na	Na	29	20			
	14.80	100	100	Na	Na	Na	66	60	Na	Na	24	21			
	17.80	100	100	Na	Na	Na	97	93	Na	Na	33	25			
	20.80	100	100	Na	Na	Na	98	98	Na	Na	32	20			
	25.50	100	100	Na	Na	Na	100	96	Na	Na	34	25			
	25.50	100	100	Na	Na	Na	98	94	Na	Na	36	26			
	27.50	100	100	Na	Na	Na	99	98	Na	Na	34	24			
	30.50	100	99	Na	Na	Na	51	48	Na	Na	23	14			
	33.50	100	100	Na	Na	Na	83	74	Na	Na	28	23			
	33.50	100	100	Na	Na	Na	36	33	Na	Na	13	10			
	36.50	100	100	Na	Na	Na	94	88	Na	Na	19	13			
	39.50	100	100	Na	Na	Na	56	52	Na	Na	4	4			
	39.50														
	45.25														
	45.25														
	52.00	100	100	Na	Na	Na	100	99	Na	Na	14	8			
	52.00														
	52.00	100	100	Na	Na	Na	90	89	Na	Na	13	9			
	52.00	100	100	Na	Na	Na	45	42	Na	Na	18	15			

		GRAIN SIZE ANALYSES % FINER (units = micrometers)											SULFUR ISOTOPES		
SITE	DEPTH	2000	1000	500	250	100	63	50	20	10	4	2	Sol S	Insol S	Total S
24	.45	100	100	Na	Na	Na	99	98	Na	Na	45	24			
	.91	100	100	Na	Na	Na	82	78	Na	Na	39	29			
	1.37	100	100	Na	Na	Na	90	89	Na	Na	37	26			
	2.29	100	99	Na	Na	Na	91	90	Na	Na	43	30			
	3.20	100	100	Na	Na	Na	93	92	Na	Na	48	36			
	4.10	100	99	Na	Na	Na	84	82	Na	Na	42	34			
	5.03	100	99	Na	Na	Na	83	81	Na	Na	41	33			
	6.40	100	99	Na	Na	Na	86	85	Na	Na	47	38			
	9.91	100	99	Na	Na	Na	87	86	Na	Na	38	28			
	16.00	100	99	Na	Na	Na	55	52	Na	Na	28	24			
	22.86	100	100	Na	Na	Na	9	8	Na	Na	4	4			
	23.50	100	99	Na	Na	Na	52	50	Na	Na	26	21			
	25.00	100	100	Na	Na	Na	69	62	Na	Na	22	17			
	28.00														
	31.40														
	35.40	100	100	Na	Na	Na	33	32	Na	Na	17	14			
	35.40	100	100	Na	Na	Na	35	33	Na	Na	20	16			
	41.40	100	100	Na	Na	Na	96	95	Na	Na	10	6			
	44.40	100	100	Na	Na	Na	42	39	Na	Na	8	5			
	50.40	100	100	Na	Na	Na	94	94	Na	Na	42	25			
	50.40														
	58.90														
	58.90	100	100	Na	Na	Na	99	96	Na	Na	9	5			
	61.90	100	100	Na	Na	Na	89	84	Na	Na	10	7			
	66.80	100	100	Na	Na	Na	27	25	Na	Na	14	11			

N.L.C. - B.N.C.
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